This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

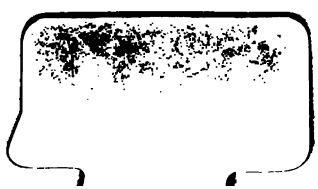
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

SCIENCE of BUILDING

E. WYNDHAM TARN.



THE SCIENCE

OF

BUILDING:

AN ELEMENTARY TREATISE

ON

THE PRINCIPLES OF CONSTRUCTION

Especially Adapted to the Requirements of Architectural Students.

By E. WYNDHAM TARN, M.A. Lond.

ARCHITECT.

ILLUSTRATED WITH FORTY-SEVEN WOOD ENGRAVINGS.

LONDON:
LOCKWOOD AND CO., 7 STATIONERS'-HALL COURT.
1870.

173. e. 28.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

PREFACE.

IN THE FOLLOWING PAGES the Author has endeavoured to introduce the Student of Architecture to a general outline of the scientific subjects connected with his Profession, an acquaintance with which can at present be only obtained by the perusal of a large number of works by various authorities. In compiling this Treatise, the Author has been careful in all cases to consult the writers who stand highest in their respective branches of knowledge; and by avoiding the use of the higher mathematics, as well as those topics which belong more especially to the engineering profession, he has brought the various subjects within the capacity of those whose mathematical attainments do not extend beyond elementry geometry and algebra.

34, MECKLENBURGH SQUARE,
LONDON.

CONTENTS.

—◆—

CHAPTER I.

MECHANICAL PRINCIPLES.

PAGE

1. Definition of Force; Mode of measuring Force . 1
2. Resultant of two or more Forces; Composition and Resolution of Forces; Triangle of Forces . . 1
3. Prof. Maxwell's Diagram of Forces . . . 3
4. Moment of a Force; the Lever . . . 4
5. Resultant of Parallel Forces; Couples . . 6
6. Centre of Gravity; to find Position of Centre of Gravity in any Body; Centre of Gravity of a Triangle; Trapezium; General Formula . . 8
7. Stability of Walls; Effect of Wind on a High Building 12
8. Diagram of Strains in Loaded Beams . . . 14
9. Shearing Force in Loaded Beams . . . 19
10. Neutral Axis in Loaded Beams . . . 20
11. Modulus of Elasticity 21
12. Moment of Inertia of an Area . . . 22

CHAPTER II.

RETAINING WALLS.

13. Pressure on Walls when the Surface of the Ground is Level; when the Surface is Inclined . . 24

CHAPTER III.

ARCHES; CUPOLAS.

PAGE

14. DEFINITIONS; GENERAL PRINCIPLES; LINE OF PRESSURES . 28
15. CIRCULAR ARCH; ITS THRUST; STRENGTH OF ABUTMENTS . 29
16. APPROXIMATE GEOMETRICAL METHOD OF FINDING THE THRUST AND STRENGTH OF ABUTMENT OF A CIRCULAR ARCH . 33
17. STABILITY OF ARCHES ARRANGED ON AN OCTAGONAL PLAN . 37
18. SEGMENTAL ARCHES; THEIR THRUST; STRENGTH OF ABUTMENTS 38
19. GOTHIC ARCHES; THEIR THRUST; STRENGTH OF ABUTMENTS 42
20. THRUST OF ELLIPTICAL ARCHES 44
21. GOTHIC VAULTING RIBS; THEIR THRUST; STRENGTH OF ABUTMENTS 44
22. OBLIQUE OR SKEW ARCHES 48
23. CUPOLAS OR DOMES; MODE OF CONSTRUCTION; THRUST; STRENGTH OF ABUTMENTS 50

CHAPTER IV.

BUILDING STONES.

24. CLASSIFICATION OF STONES; GRANITE 55
25. SANDSTONES 57
26. LIMESTONES 59
27. OOLITES 59
28. MAGNESIAN LIMESTONES 60
29. POROSITY OR ABSORBENT POWER OF STONES . . 60
30. MORTAR; CEMENT 61
31. RANSOME'S CONCRETE STONE; PROTECTION OF STONE FROM WEATHER 62
32. BEDS OF STONES 63

CHAPTER V.

TIMBER.

PAGE

33. GROWTH OF TIMBER TREES 64
34. DECAY OF TIMBER; SEASONING; VENTILATION . . 66
35. STRENGTH OF TIMBER; TRANSVERSE STRAIN . . 67
36. DEFLEXION OF HORIZONTAL BEAMS . . . 71
37. STRENGTH OF LONG PILLARS OF WOOD . . . 74
38. CRUSHING STRENGTH OF TIMBER 76
39. TENSILE STRENGTH OF WOOD 77
40. TIMBER TRUSSES; STRAINS ON SEVERAL PARTS OF A TRUSS 77
41. WEIGHT SUPPORTED BY ROOFS; SCANTLING OF TIMBERS EMPLOYED IN A ROOF TRUSS 81
42. CENTERINGS FOR ARCHES 82

CHAPTER VI.

IRON.

43. DIFFERENT KINDS OF IRON; CAST-IRON; CAST-IRON BEAMS; HODGKINSON'S FORMULA 84
44. LONG CAST-IRON COLUMNS 87
45. SHORT CAST-IRON COLUMNS 89
46. WROUGHT-IRON; RESISTANCE TO EXTENSION; LONG COLUMNS; SHORT COLUMNS 91
47. WROUGHT-IRON BEAMS; ROLLED JOISTS; PLATE GIRDERS 92
48. LATTICE GIRDERS 96
49. ELASTICITY OR TENSILE STRENGTH OF IRON BARS . 97
50. DEFLEXION OF WROUGHT-IRON BEAMS . . . 98
51. EXPANSION AND CONTRACTION OF IRON BY CHANGE OF TEMPERATURE 100
52. WROUGHT-IRON ROOFS; METHODS OF CALCULATING STRAINS ON DIFFERENT PARTS 101
53. DIAGRAM OF STRAINS APPLIED TO ROOFS . . . 103
54. STEEL; ITS NATURE AND STRENGTH . . . 104

CHAPTER VII.

WATER CONTAINED IN VESSELS AND PIPES.

PAGE

55. PRESSURE OF WATER ON THE SIDES AND BOTTOM OF TANKS, ETC. 108

56. CENTRE OF PRESSURE; STRENGTH OF RESERVOIR WALLS . 109

57. WATER IN VESSELS WHICH COMMUNICATE; HYDRAULIC LIFTS, 111

58. SPECIFIC GRAVITY; SUBSTANCES HEAVIER THAN WATER; SUBSTANCES LIGHTER THAN WATER . . . 112

59. FLOW OF WATER THROUGH PIPES; LOSS OF HEAD; AMOUNT OF DISCHARGE 114

APPENDIX.

TABLE OF SPECIFIC-GRAVITY AND WEIGHT PER CUBIC FOOT OF BUILDING MATERIALS . . . 117

Errata.

Contents, page v. tenth line from bottom, *for* page 12 *read* page 13.
,, page vii. second line from bottom, *for* page 103 *read* page 104.
,, page vii. bottom line, *for* page 104 *read* 105.

Page 32, second line from top, supply the sign − before $\frac{3\,h^2}{16}\,r$
,, 38, bottom line, supply letter l at end of line.
,, 46, ,, supply sign + before $\cdot 75h^2 \,.\, r$
,, 47, fifth line from top, supply sign + before $\cdot 68h^2$
,, 52, bottom line, supply the sign + between $(3rt^2 \quad t^3)$
,, 70, tenth line from bottom, supply sign = before 44587 lbs.
,, 75, second line from bottom, *for* $a\frac{d^4}{l^2}$ *read* $a\frac{d^4}{l^2}$

a body may be represented by straight lines whose lengths are proportional to the forces, and whose directions are those in which the forces act.

2. RESOLUTION OF FORCES.—Whatever number of forces act upon a body, it is clear that they can only move it in *one* direction, so that their total effect must be

THE SCIENCE

OF

BUILDING.

CHAPTER I.

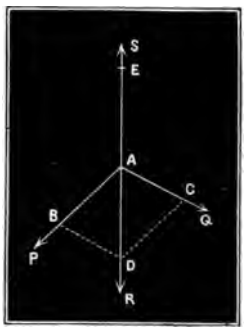
MECHANICAL PRINCIPLES.

1. THE SCIENCE of 'mechanics' investigates the laws of forces and their effects upon various bodies. The term 'force' is applied to whatever causes or *tends* to cause motion, or a change of motion in bodies, and is measured by reference to some unit of weight, as pounds, tons, &c. When a body is set in motion by a force, the effect of the force is measured by the velocity generated in an unit of time. When two or more forces act upon a body, but do not produce motion, the body is said to be in *equilibrium* by the action of those forces. The relative magnitude of the forces acting on a body may be represented by straight lines whose lengths are proportional to the forces, and whose directions are those in which the forces act.

2. RESOLUTION OF FORCES.—Whatever number of forces act upon a body, it is clear that they can only move it in *one* direction, so that their total effect must be

equal to some one force acting in that *one* direction. This force is called the 'resultant' of all the forces which act on the body, and if a force equal in magnitude to the resultant and opposite in direction is applied to the body it will be kept in equilibrium. Suppose the two forces P and Q (fig. 1) represented in magnitude and direction by the lines A B and A C, to act on a body A; draw C D parallel to A B, and B D parallel to A C; join A D; then the line A D represents the resultant (R) of P and Q in magnitude and direction. Produce the line D A and take A E equal to A D, then E A will be the magnitude of the force (S) acting on A, which will just balance P and Q.

Fig. 1.



The forces P and Q are called the 'components' of the force R. If the single force R acts on the body A in the direction A D, and we want to know its effect in any two other given directions A B and A C, we take A D to represent R and make it the diagonal of a parallelogram whose sides are parallel to the given directions of AB and AC, then these sides will represent in magnitude the effect of R in those two directions.

When more than two forces act on the body at A, we can obtain the value and direction of their resultant by first finding that of any two of the given forces, and then considering those two as replaced by their resultant; then find the resultant of this last force combined with another of the given forces, and so on for all the forces, until at last we reduce them to a single

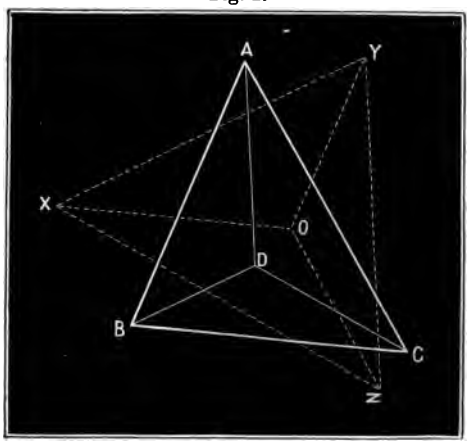
force, which will be the resultant required. When the body A is kept in equilibrium by the three forces P, Q, and S, represented by the lines A B, A C, A E; these forces are proportional each to the sine of the angle contained between the other two; that is to say:

$$\frac{P}{\sin. QAS} = \frac{Q}{\sin. PAS} = \frac{S}{\sin. PAQ}.$$

Also if we form the triangle A B D of lines drawn in the directions of the forces, it is evident that these lines will represent the forces in magnitude and direction, if taken in order. That is to say, P is represented by A B, acting from A towards B; Q by B D, acting from B towards D; S by D A, acting from D towards A. And conversely, if three forces acting at a point are represented by the sides of a triangle, taken in order, they will balance each other.

It is also clear that in order that three forces may balance each other or be in equilibrium, their directions must meet in one point.

Fig. 2.

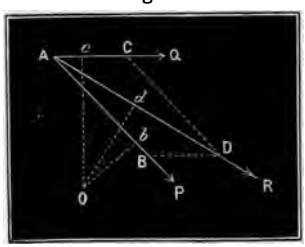


3. Let ABC (fig. 2) be a triangular piece of framework jointed at A, B, and C, and kept in equilibrium by the action of three forces acting at the joints. Since there is equilibrium the

directions of these forces must meet at some point, D, and must also be proportional to the sides of a triangle which are respectively parallel to the lines AD, BD, CD. Let XYZ be such a triangle. Then to find the stresses in AB, BC, CD arising from the forces, draw lines from the points X, Y, Z parallel respectively to the sides of the triangle ABC; these will meet in a point O, and the line XO will represent the stress in BC; YO that in AB; ZO that in AC; to the same scale as that on which the sides of the triangle, XYZ, represent the original forces acting at the joints A, B, C. The figure ABC is called the 'frame diagram,' and the figure XYZ the 'stress diagram.' The lines which in the former make a closed polygon are represented in the latter by lines meeting in a point, and vice versâ; so that they may be called *reciprocal figures*. This is the basis of the method of diagrams applied by Prof. Maxwell to the determination of the relative values of the stresses on the several parts of any framework, such as a roof-truss, lattice-girder, &c. (See paper by J. C. Maxwell read at meeting of British Association, 1867.)

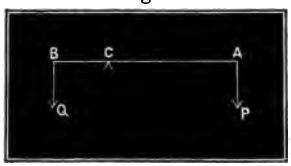
4. MOMENTS.—It is often necessary in the solution of mechanical problems to ascertain the effect of a force upon a body with respect to some point through which its direction does *not* pass. Let the forces P, Q, and R act at A (fig. 3), and be represented by the lines AB, AC, AD. Let O be some point which is not in the direction of

Fig. 3.



either of these forces; draw O*b* perpendicular to AB; O*c* to AC; O*d* to AD; then the product of the force P into the length O*b* is called the 'moment of P about O;' the product of Q into O*c* is the *moment of Q about O*; and the product of R into O*d* is the *moment of R about O*. Moreover, by the principles of geometry it can be proved that the moment of the resultant R about O is equal to the *sum* of the moments of P about O and of Q about O. The *moment* of a force about any point measures its tendency to produce rotation round that point. Whenever two forces act in any directions upon a body having a fixed point, they will be in equilibrium if their moments about the fixed point are equal, but tending to rotation in opposite directions. Thus, if we have a straight rod AB (fig. 4) resting on a fixed point C, and a weight P is applied at one end A, and a weight Q at the other end B, these weights will balance each other if $P \times AC = Q \times BC$.

Fig. 4.



In this we have the principle of the lever, for by moving C, the fulcrum, near to B we can make a small weight at A balance a large one at B. The weight P which will balance a given weight Q is determined by the equation

$$P = \frac{BC}{AC} \times Q.$$

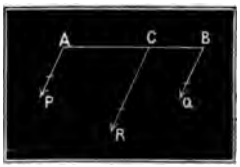
If the fulcrum C is placed at one end of the lever, and Q acts at a point B between A and C, the forces P and Q must be in opposite directions in order that they may

balance, but the same relation exists between them; that is to say, $P \times AC = Q \times BC$.

The theory of moments is constantly applied in all the investigations into the principles of scientific construction, and therefore requires to be thoroughly understood by the architect.

5. COUPLES.—When two parallel forces P and Q act on a body in the same direction but at different points A and B (fig. 5), their resultant R is equal to their sum, and acts at a point C which is determined by the equation,

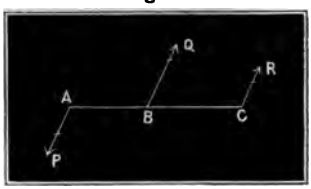
Fig. 5.



$$P \times AC = Q \times BC.$$

If the forces P and Q act in opposite directions (fig. 6) (Q being greater than P) the resultant R is equal to their difference and acts in the direction of the greater force at a point C, determined as before by the equation,

Fig. 6.



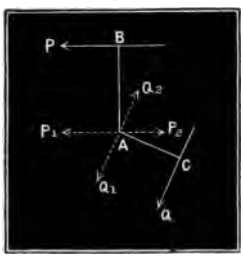
$$P \times AC = Q \times BC,$$

$$\text{or } AC = \frac{Q}{Q - P} \times AB.$$

From this it will be seen that as P and Q approach equality, the point C goes further and further away, so that when P = Q, C is at an infinite distance, or there is no point of application of the resultant. The two equal and parallel forces acting at A and B in the same plane, now constitute what is termed a 'couple;' and the moment of P about B, or of Q about A, is called

the *moment of the couple.* The effect of a couple is to communicate an angular motion about an axis perpendicular to the plane in which its forces act, which axis passes through the *centre of gravity* (G) of the body. Two couples which act upon a body in the same plane, but in opposite directions, will be in equilibrium if their moments are equal. The effect of a couple upon a body is not altered by increasing or diminishing the forces of the couple, provided the length of its arm is diminished or increased in like proportion, so that the moment, or product of the force into the length of the arm, remains the same. The principle of couples enables us to shift the point of application of any forces acting on a body to a point about which they balance, which is often required in mechanical problems, and enables us to simplify their solution. Suppose P and Q (fig. 7) to be two forces acting in the same plane on a body, and that their moments balance about a point A, so that

Fig. 7.



$$P \times AB = Q \times AC,$$

AB being perpendicular to the direction of P, and A C to that of Q. If we apply at A two equal and opposite forces, each equal and parallel to P, and call them P_1 and P_2, we shall not disturb the equilibrium: also if we apply at A two equal and opposite forces, Q_1 and Q_2 each equal and parallel to Q, the equilibrium is undisturbed. We now have the couples P. BA. P_2 and Q. CA. Q_2 acting in opposite directions, and having

equal moments, so that they balance each other, and can be removed without affecting the equilibrium. We have, therefore, remaining only the forces P_1 equal to P, and acting parallel to its direction; and Q_1 equal to Q also acting parallel to its direction; and these both act at the point A. Hence it follows that if two forces, acting in any direction on a body, balance each other about any point in that body, they may be transferred to that point where they may be considered as acting with the same force as before, and in directions parallel to their original ones; and their effect upon the body is the same as before. This is an important principle in the investigation of the effect which the thrust of an arch produces on its supporting pier. (**15**)

6. CENTRE OF GRAVITY.—When two parallel forces act upon a body, we have seen in the last article that the point at which their resultant acts is found by equating their moments about that point. In the same way the position of the resultant of any number of parallel forces can be determined, by first finding the resultant of any two of the forces, and then of that first resultant and a third force; and so on until there is only one force left, which is the resultant of all the forces. Now every solid body which is subject to the action of the earth's attraction, may be considered as consisting of a number of heavy particles, the weights of which are parallel forces acting vertically downwards. There is therefore a point in every body about which all these parallel forces balance, and through which their resultant passes; this point is called the 'centre of gravity' of the body. This statement is

only strictly true for bodies which are very small as compared with the diameter of the earth, for the direction in which gravity acts is towards the *centre* of the earth, and the force of gravity also varies according to the latitude of the place; but as we have only comparatively small objects to deal with, we can, without any perceptible error, consider that the action of gravity on any solid body is perpendicular to the surface of still water at that place, and is also uniform in force throughout the body. The position of the *centre of gravity* of any body is the same whatever may be the intensity of the force of gravity, and does not vary with change of position. In the case of a rigid body, we may in all mechanical investigations, consider that its whole weight is collected at its centre of gravity, and if this point is supported, the whole body is in equilibrium.

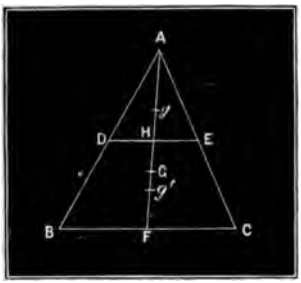
If a body is hung up loosely by any point, so that it can turn freely about that point, the centre of gravity will always be in a vertical or plumb-line dropt from the point of suspension; hence we can readily find the position of the centre of gravity in an irregular plane figure by suspending it at two points, and the intersection of the plumb-lines dropt from each point will give us the position of the centre of gravity.

In all regular figures, whose material is homogeneous, the centre of gravity is in the centre of the figure; as in the circle, ellipse, polygon of equal sides, sphere, ellipsoid, and all regular solids. In the square and parallelogram it is at the intersection of the diagonals drawn from opposite corners. In any triangle its posi-

tion is found by bisecting one side and joining the point of bisection with the opposite vertex, and measuring one-third of this last line from the bisected side, or two-thirds from the vertex.

Knowing the position of the centre of gravity (G) in a triangle A B C (fig. 8) we can find that (g') of a part B C E D, cut off by the line D E parallel to B C. The centre of gravity of the smaller triangle A D E is g on the line A F and is found as above. Let g' be the centre of gravity of the part B C E D, this will also be on the line A F (the point F bisecting B C). We may now consider the weight w of the triangle A D E as acting at g, and the weight w' of the figure B D E C as acting at g'; then the moments of their weights must balance about G, so that

Fig. 8.



$$w \times gG = w' \times Gg', \text{ or } Gg' = \frac{w}{w'} Gg.$$

Now since w and w' are proportional to the areas of the figures, we may put the ratio of the areas for that of the weights. If A is the area of the whole triangle, a that of the smaller one, we have,

$$Gg' = \frac{a}{A - a} Gg.$$

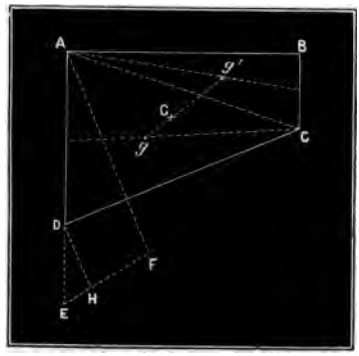
Example.—Let $AE = \frac{1}{2} AC$; then $A = 4a$

$$Gg = \tfrac{1}{3} AF, \therefore Gg' = \tfrac{1}{3} Gg = \tfrac{1}{9} AF$$

$$Fg' = FG - Gg' = \tfrac{1}{3} AF - \tfrac{1}{9} AF = \tfrac{2}{9} AF.$$

Another method of finding the centre of gravity of a trapezium, is to divide it into two triangles, then join their centres of gravity, and the distance of the centre of gravity of the figure from that of any one of the triangles is inversely proportional to the areas of the triangles. Thus if g is the centre of gravity of one triangle whose area is A (fig. 9), g' that of the other whose area is a, G the centre of gravity of the trapezium and situate in the line gg', its position is determined by the equation,

Fig. 9.



$$A \times Gg = a \times Gg', \text{ or } Gg' = \frac{A}{a} Gg,$$

so that we have to divide the line gg' in the proportion of the two areas A and a.

Example.—Let fig. 9 represent a trapezium having the two sides A D and B C perpendicular to A B; join A C; then the areas A and a are as the bases A D and B C; let g' be the centre of gravity of the triangle, A B C, and g that of A C D; join gg'. Produce A D to E, making D E equal to B C; at E draw a line E F, making any angle with A E, and take E F = gg'; join A F, and draw D H parallel to A F; then E F is divided in the ratio of A : a; and G is found by making gG = EH.

The general formula for the centre of gravity of a

body which can be divided into two parts whose masses are M_1, and M_2, is

$$x = \frac{M_1 x_1 + M_2 x_2}{M_1 + M_2}$$

where x, x_1 and x_2, are the distances of the centres of gravity of the whole and of the two parts respectively, measured from any fixed point that may be most convenient. Or if x_1 is required,

$$x_1 = \frac{(M_1 + M_2)\, x - M_2 x_2}{M_1}.$$

Example.—Apply this formula to find g' in fig. 8, the point A being that from which x is measured; then since the masses of the triangles are as the squares on AF and AH,

$$Ag' = x_1 = \tfrac{2}{3} \frac{AF^3 - AH^3}{AF^2 - AH^2},$$

and if $AH = \frac{1}{2}\, AF$,

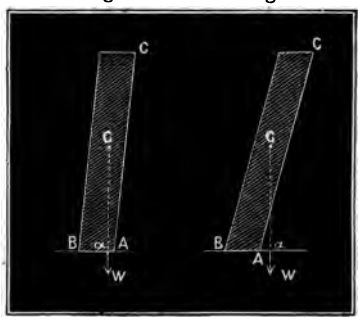
$$Ag' = \tfrac{2}{3} \frac{1 - \frac{1}{8}}{1 - \frac{1}{4}} AF = \tfrac{7}{9}\, AF$$

$$\therefore Fg' = AF - Ag' = \tfrac{2}{9}\, AF.$$

To find the centre of gravity (G) of any solid pyramid or cone whose vertex is A. First find g the centre of gravity of the base; join Ag, and take $gG = \frac{1}{4}\, Ag$. That of a thin hollow cone is found by taking $gG = \frac{1}{3}\, Ag$. That of a solid hemisphere is found by measuring $\frac{3}{8}$ of the radius above the centre. That of a thin hollow hemisphere is half way between the centre and the vertex.

7. If a plumb-line dropt from the centre of gravity of a body falls *within* the base, that body is in a condition of stability, but if any force is applied to it which causes the plumb-line to fall *outside* the base, the body will be overturned. Let figs. 10 and 11 represent the section of a wall which is out of the perpendicular; the weight W acting at the centre of gravity will have a moment about A, W × Aa, which in fig. 10 tends to keep it from falling, and in fig. 11 tends to overturn it.

Fig. 10. Fig. 11.



If a force F, such, for example, as that of the wind, is brought to bear on the wall in fig. 10, it will have a moment, F × $\frac{1}{2}$ AC, tending to overturn the wall about A; and if the value of this moment is greater than that of the moment W × Aa, the wall will fall over. The pressure of the wind on a vertical surface is sometimes as great as 55 lbs. per square foot, and its resultant may be taken as acting at the middle of the wall. If, then, h is the height of the wall, the pressure of the wind (F) at the middle for one foot length of wall is $55h$; and the moment of F about A is $55\,\frac{h^2}{2}$.

Let w be the weight per cubic foot of the wall, t its thickness, Aa = x; then the moment of the weight about A is $w.h.t.x$; if this is greater than $55\,\frac{h^2}{2}$ the wall will stand, and if less it will fall over. For example,

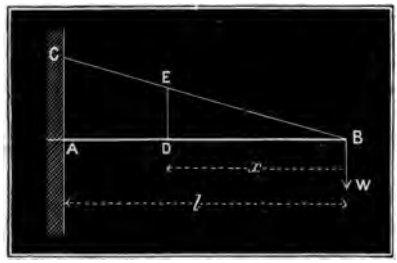
let $h = 40$ ft., $t = 5$ ft., $w = 110$ lbs. When the two forces just balance, we have

$$55 \tfrac{1600}{2} = 110 \times 40 \times 5 \times x; \text{ or } x = 2 \text{ ft.}$$

Therefore, in this case the plumb-line from G must fall more than 2 ft. within the base, otherwise the wall will be blown down by a storm of wind exerting a force of 55 lbs. per square foot of surface; so that the top of the wall must not in this case project more than 12 in. beyond the base A. The stability of a lofty factory chimney may be determined in this manner. Rankine states that the pressure of the wind on a circular chimney stalk is half that on a square one of the same diameter ('Applied Mechanics').

8. STRAINS.—Let AB (fig. 12) be a beam of length (l) fixed in a wall at A, and loaded with a weight (W) at B. Then the 'strain' upon any part D of the beam at distance x from B is by (4) represented by the moment of the weight (W) about the point D; that is, if we call M the strain at D, we have

Fig. 12.



$$M = W . x$$

and the strain at the point A, next the wall, is

$$M = W . l$$

The strain, therefore, at any point is proportional to its distance from B. If we take CA vertical and make

it represent the value of W.l on any convenient scale, and join C B, then the ordinate D E at any point (D) will represent the strain (W . x) at that point to the same scale as A C represents W . l.

Suppose the weight (W) instead of being applied at one end of the beam A B, to be distributed uniformly over its entire length, w being the weight per unit of length, so that $w \cdot l = W$. Then the weights acting on each unit of length will be so many equal and parallel forces, and their resultant (**5**), which is equal to their sum, must act at the middle of the beam. Now W equals the sum of all these forces, and its point of application is therefore at the centre of the beam. Therefore the strain upon the point A is

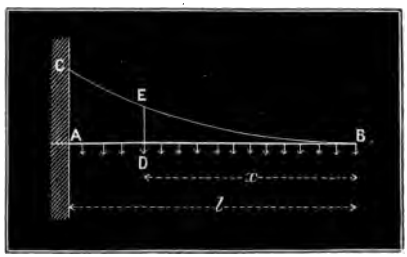
$$M = W \times \frac{l}{2} = \frac{w}{2} l^2$$

The strain upon any other point D of the beam at distance x from B is

$$M = \frac{w}{2} x^2$$

If, then, we draw A C (fig. 13) vertical and make it represent on any scale the value $\frac{1}{2}$ W . l, and draw a parabola C B having its vertex at B, the ordinate D E at distance x from B will represent to the same scale the value of the strain at the point D.

Fig. 13.



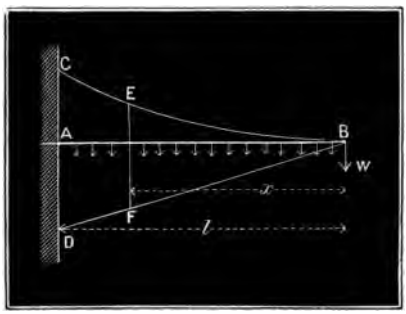
If A C does not exceed $\frac{1}{4}$ A B,

an arc of a circle may be substituted for the parabola BC.

Comparing the strain produced by the weight W concentrated at B, with that produced by the same weight uniformly distributed, we see that the strain in the former case on any point is double the strain in the latter case, so that a beam will bear twice as much load when it is uniformly distributed as it will when concentrated at one end.

When the beam AB is loaded at one end with a weight W, and has also a distributed load $w \cdot l$ to bear, the diagram representing the strain at any point is a combination of the two previous figures. In fig. 14 let DAC be drawn at right angles to AB, take AD equal to $W \cdot l$, AC equal to $\frac{1}{2} w \cdot l^2$. Draw the parabola CB, or an arc of a circle if AC is less than $\frac{1}{4}$ AB, and join DB. Then the strain at any point at distance x from B is represented by the ordinate EF. The moment of the strain at that point is

Fig. 14.



$$M = W \cdot x + \tfrac{1}{2} w \cdot x^2.$$

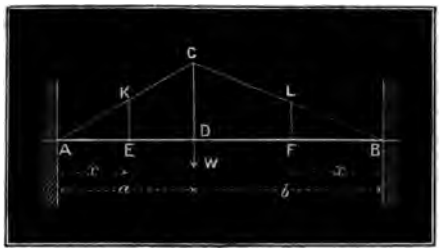
And the moment of the strain at A is

$$M = W \cdot l + \tfrac{1}{2} w \cdot l^2.$$

Now take the case of a beam AB (fig. 15) supported at the two ends and loaded at any intermediate point

D at distance a from A, and distance b from B. Suppose the forces P and Q represent the vertical reactions at A and B caused by the weight W. Then

Fig. 15.



if the point where W acts is supposed to be a fixed fulcrum, and weights equal to P and Q are placed at A and B, the beam will be strained in the same manner as at first supposed, and Q . b will be the strain at D. Also by taking moments about A we have

$$Q \cdot l = W \cdot a, \text{ or } Q = W \frac{a}{l}.$$

Therefore the strain at D $= Q \cdot b = W \times \frac{a \cdot b}{l}$.

If x is the distance from A or B of the points E or F, the strain at the point E is

$$M = W \frac{x \cdot b}{l}$$

and the strain at the point F is

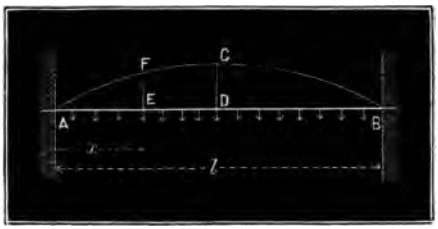
$$M = W \frac{x \cdot a}{l}.$$

To draw the diagram of strains, take DC vertical and equal on scale to W $\frac{ab}{l}$; join CA, CB, then the ordinates EK, FL represent the strains at E and F.

If the point D is the middle of the beam, the strain at that point is $\frac{1}{4}$ W . l; since $a = b = \frac{1}{2}l$, and the strain at E or F is $\frac{1}{2}$ W . x.

Let the weight (W) be uniformly distributed over the whole length of the beam AB (fig. 16). Then it

Fig. 16.



can be shown by reasoning, similar to that just employed, that the strain at any point E at distance x from A or B is

$$M = \frac{W}{2} \times \frac{x(l-x)}{l} = \tfrac{1}{2} w \,.\, x\,(l-x)$$

if w is the weight per unit of length; the strain at D is found by making $x = \frac{1}{2}l$, and is

$$M = \tfrac{1}{8} W \,.\, l = \tfrac{1}{8} w \,.\, l^2.$$

Comparing this with the last example, we see that the strain at the centre, when W is concentrated there, is twice as great as when it is uniformly distributed.

To draw the diagram for the strains produced by a distributed weight at any part of the beam, take DC to represent on scale the quantity $\frac{1}{8}$ W . l, draw a parabola ACB having its vertex at C; or if DC is not more than $\frac{1}{8}$ AB, a circular arc with its centre on the line CD produced may be substituted without

material error. Then the ordinate EF will represent the strain at any point E, to the same scale as DC is drawn.

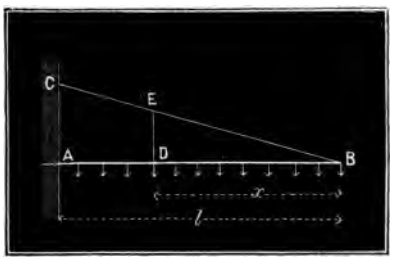
The methods of drawing diagrams of strains in several other arrangements of load will be found in Humber's 'Handy-book of Strains,'* but the above-mentioned are the principal ones that occur in ordinary buildings.

9. SHEARING.—There is another kind of strain which is produced in a loaded beam, called the 'shearing force,' or the *vertical* action of the straining weight transmitted along the whole length of the beam, and tending to cause contiguous portions or sections to slide vertically upon each other.

When a beam is fixed at one end and loaded at the other with a weight W, that weight represents the *shearing force* produced at every point along the beam.

If the weight ($W = w\ l$) is uniformly distributed along the beam AB (fig. 17), so that w is the weight on each unit of length; then the *shearing force* at any point D at distance x from B is $w\ .\ x$, which is the load on the part of the beam between B and D. And the *shearing force* at A is W. If we take the vertical line AC to represent W, and join CB, then the ordinate DE will represent the *shearing force* at any point D.

Fig. 17.

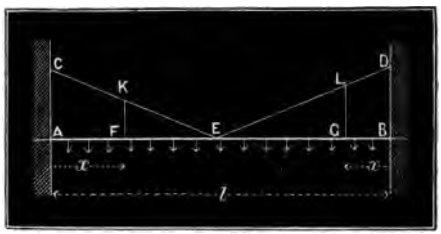


* Lockwood and Co., London, 1869.

When a beam AB of length l is supported at each end, and loaded with a weight W at any point C, at distances a and b from A and B, the *shearing force* developed at every point between C and A will be represented by $W \frac{b}{l}$; and at every point between C and B by $W \frac{a}{l}$. If C is the middle of the beam, then $a = b = \frac{1}{2} l$, and the *shearing force* at every point will be $\frac{1}{2}$ W.

When a beam AB (fig. 18) of length l is uniformly loaded with a weight ($W = w \, . \, l$), the *shearing force* at

Fig. 18.



A and B will be represented by $\frac{1}{2} w \, . \, l$, and at any point at distance x from either end it will be represented by $w (\frac{1}{2} l - x)$. Therefore at the centre, where $x = \frac{1}{2} l$, the *shearing force* will be zero. If, then, the verticals AC and BD are taken to represent the quantity $\frac{1}{2}$ W, and we join CE and DE, the ordinate FK or GL will represent the *shearing force* at F or G.

10. NEUTRAL AXIS. — Whenever a beam of any elastic material is supported at its two ends in a horizontal position, and loaded in the middle, it is subjected to a transverse strain, whereby the fibres or particles in the upper part are compressed, whilst

those in the lower part are extended. Also the fibres nearest the top are more compressed than those lower down in the beam; and the fibres near the bottom are, on the other hand, more extended than those which are higher up. Hence it follows that there must be a layer of fibres or particles in the interior of the beam, which is neither extended nor compressed; and this layer is called the 'neutral surface' of the beam. If we take a vertical section through the middle of the beam, the line in which the neutral surface cuts that section is called the 'neutral axis,' and may be considered as passing through the centre of gravity of the section, provided the strain upon the beam is not sufficient to injure its elasticity. Some very carefully-made experiments by Mr. Barlow* show that in cast-iron beams of rectangular section the neutral axis is at the centre of the section of the beam, even when strained with weights amounting to three-fourths of the breaking weight, and that its position is not sensibly altered by variations in the amount of the strain applied.

11. ELASTICITY.—When an elastic substance is strained by a force applied in any manner, it will be found that its dimensions are altered during the application of the force; and that when the action of the force ceases, it will return to its original dimensions, provided the strain has not exceeded a certain limit, called the 'limit of elasticity.' If we take a prism of any material having one square inch of section, and subject it to a longitudinal strain by a force F, the change in its length will

* *Philosophical Transactions*, 1855, 1857.

be proportional to the amount of force applied, as long as the *limit of elasticity* is not exceeded. Let l represent the original length, x the change in length produced by the force F, E a constant depending on the nature of the material of which the prism is composed; then it is found that,

$$x : l :: F : E$$

$$\text{or, } E = F \times \frac{l}{x}.$$

The constant E is called the 'modulus of elasticity,' and its value is determined by experiment for various substances.

12. MOMENT OF INERTIA.—If we suppose any area or plane surface to be divided into a very large number of indefinitely small particles, and call a the area of any one of such particles, r its distance from any given line or axis, then the product $a.r^2$ is called the 'moment of inertia' of that particle about the given axis, and the *moment of inertia* of the whole surface is the *sum* of all possible values of $a.r^2$. This is found by means of the integral calculus when the outline of the surface is a known geometrical figure. The formulæ for the *moment of inertia* of various geometrical figures is given in treatises on dynamics with respect to various axes. In the present work we shall only require to know it for two simple figures, and the axis will be taken through the centre of gravity.

Let the area of the figure be rectangular having the depth d and breadth b; then the *moment of inertia* (I) of a rectangle is found to be

$$I = \tfrac{1}{12}\, b d^3.$$

If we have a hollow rectangular figure or a beam of I section (figs. 38, 39, 40) * in which t is the total thickness of the web or vertical portion, d_1 the clear depth between the top and bottom flanges, we find the moment of inertia to be,

$$I = \tfrac{1}{12}\,(b.d^3 - (b-t)\,d_1^3).$$

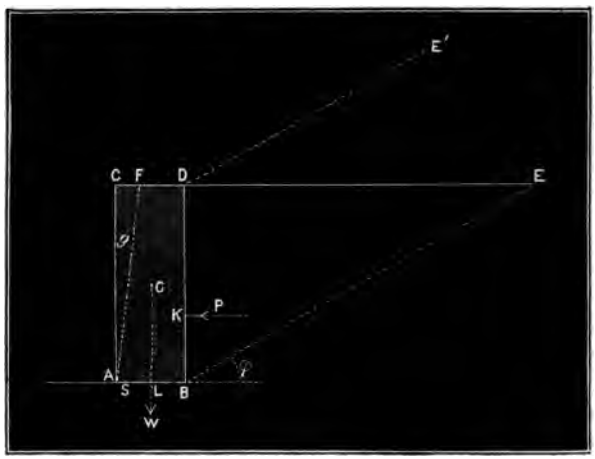
* Page 94.

CHAPTER II.

RETAINING WALLS.

13. When an embankment of earth is left to itself it assumes a gradual incline, which is called its *natural slope*; and the angle which this slope makes with the horizon varies according to the adhesive qualities of the component parts of the soil, being about 30° for loose earth and 45° for stiff clay. When, therefore, earth is filled up against a vertical wall, the pressure sustained by the wall is that of the wedge of earth which lies above the *natural slope*. Thus, in fig. 19, if AD is the

Fig. 19.



section of a wall against which the earth is filled up,

BE the *natural slope* making the angle ϕ with the horizontal, the wall has to support the pressure of the triangular mass of earth BDE. The pressure (P) of the earth is perpendicular to the face B D of the wall, and its resultant acts at a point K, one-third of its height from the base, or $BK = \frac{1}{3} BD$. Let h be the height BD, t the thickness AB, supposed uniform, w the weight of a cubic foot of earth, w' that of a cubic foot of the wall. It is demonstrated* that the pressure on one foot length of wall is,

$$P = w \frac{h^2}{2} \tan.^2 \left(\frac{DBE}{2}\right)$$

so that when $\phi = 30°$, $P = \frac{1}{6} w h^2$
and when $\phi = 45°$, $P = \cdot 086\ w h^2$.

This force P tends to overturn the wall about its outer edge A, and the force which resists it is the weight W of the wall itself acting at G, its centre of gravity; the moments therefore of W and P, taken about A, must balance each other in order that the wall may be in equilibrium. In practice, however, it will not do for a wall to be only just in equilibrium with the forces acting on it; and to secure stability, it is usual to take the moments about a point S within the base, where $AS = \frac{1}{3}t$.

The moment of P about S is $\frac{1}{3}$ P.h, or

$$\frac{1}{18} w h^3, \text{ when } \phi = 30°,$$

and $\frac{\cdot 086}{3}\ w h^3$, when $\phi = 45°$.

The moment of W about S is $\frac{3}{8} w' h t^2$; and if we

* Rankine's *Applied Mechanics.*

put $\frac{w'}{w} = \frac{5}{4}$ and equate the moment of P with that of W, we find

$$t = \cdot 3444h, \text{ when } Q = 30°$$
$$t = \cdot 2473h, \text{ when } Q = 45°.$$

Therefore to find the thickness of a retaining wall multiply the height by ·3444 for loose earth whose *natural slope* is 30°, and by ·2473 for stiff clay, or other adhesive material whose *natural slope* is 45°.

If we take CF = 3AS, and make AF the face of the wall, we shall find that the centre of gravity (g) of this wedge is exactly over S, so that the value of the moment of its weight about S is zero; but the wall will still have the same stability or power of resisting the force P, while $\frac{3}{13}$ths of the masonry will be saved. In this case the position of G has been shifted further back, so that the lever arm SL of W is increased in the same proportion as W itself is decreased, or the moment of W about S remains unaltered. The thickness of wall here given is on the supposition of the perfect cohesion of its materials so as to form a solid mass.

If the surface DE′ of the earth is inclined to the horizontal at the *natural slope* or angle ϕ, the resultant pressure P will act at K in a direction parallel to the surface, or making also the angle ϕ with the horizontal. The value of P is found by mathematical investigation to be,

$$P = \frac{w}{2} h.^2 \cos. \phi;$$

and as its direction is not perpendicular to the wall, but

inclined at an angle $90° - \phi$, we must resolve it into its vertical and horizontal components V and H; then we find that when

$$\phi = 30°,\ V = \frac{\sqrt{3}}{8}\, w.h^2,\ H = \tfrac{3}{8}\, w.h^2,$$

$$\phi = 45°,\ V = \frac{w}{4}\, h^2, \qquad H = \frac{w}{4}\, h^2.$$

The moment of V about S acts in the same direction as that of W, so that it assists the weight of the wall in resisting the thrust; then the value of t is found from the equation,

$$W\tfrac{3}{8}\, t + V\tfrac{7}{8}\, t = H\frac{h}{3};$$

from which we obtain,

$$t = \cdot 3525\, h, \text{ when } \phi = 30°$$
$$t = \cdot 2486\, h, \text{ when } \phi = 45°.$$

Therefore to find the thickness of a retaining wall of rectangular section, which supports earth whose surface slopes up from the top of the wall at the *natural slope* or angle ϕ, multiply the height by ·3525 when $\phi = 30°$, and by ·2486 when $\phi = 45°$.

CHAPTER III.

ARCHES; CUPOLAS.

14. THE ARCH, which we now propose to consider, is a structure consisting of a number of wedge-shaped stones called 'voussoirs,' arranged in the form of a circle or other geometrical figure, resting upon two piers, and carrying a wall or other superstructure. These voussoirs are kept in their place by their mutual pressures which are brought into play by their own weights, together with that of the superstructure, and by the resistance offered by the piers or abutments. If a straight line is drawn through the bed joint of each voussoir which shall represent the resultant of the pressures upon that joint, a polygon will be formed by the lines representing the several resultants; and the curve which touches all the sides of the polygon is the 'line of pressures' of the arch, and the points where it cuts the joints are the 'centres of resistance.' If we divide the depth of the joints into three equal parts, the *centres of resistance* must lie in the *middle* division, in order that the joint may not have any tendency to open either at its outer or inner edge. Also the *line of pressures* must fall within the thickness of the piers. The depth of the voussoirs must also exceed

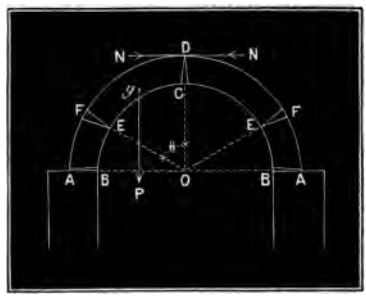
one-thirtieth of the span in a semi-circular arch, otherwise the arch will give way by the opening of the joints. It is also necessary that the mean pressure upon any joint shall not exceed one-twentieth of the ultimate resisting power of the material composing the voussoirs.

If a transverse section is made of a cylindrical arch, the inner curve is called the 'intrados,' and the outer curve the 'extrados.'

15. The main object aimed at in the investigations of the arch, is to find what thickness must be given to the abutments in order that they may be strong enough to resist the thrust of an arch, in which the span and depth of the voussoirs is known, as well as the height of the piers and of the superstructure.

In order to understand the method of investigation, we must first examine how an arch will break up or give way if overloaded, or if the piers are too weak to sustain it. In fig. 20 we have the section of a circular arch resting on two piers; this arch we may consider as consisting of two equal parts divided by the vertical line through the centre, and balancing each other by their mutual resistance at CD. If this arch is overloaded or the piers are built too thin to resist the outward thrust, which the voussoirs produce by their mutual pressures, the centre will sink, and the haunches will rise at EF, so that the arch will tend to break up into four

Fig. 20.



parts; by the opening of the joint CD at C, of EF at F, and of the springing joint AB at B; hence it appears that when the arch is about to fall, the whole thrust at the crown, which we will call N, acts at the point D. The joint EF is evidently that at which the effect of the thrust N is greatest, and its exact position can be determined by mathematical investigation. For if P is the weight of the portion between EF and CD, acting at g its centre of gravity, and its moment about E is $P \cdot x$, while that of N is $N \cdot y$, we have only to equate these moments,

$$N \cdot y = P \cdot x, \text{ or } N = P\frac{x}{y},$$

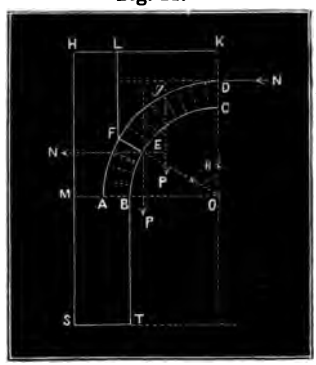
and then calculate the value of N for different values of the angle θ which FE makes with CD, and we shall find what value of θ makes N greatest.

The algebraical expression for the value of N is rather complicated, and the full investigation will be found in Captain Woodbury's 'Treatise on the Arch,' and Fenwick's 'Mechanics of Construction.'

It is there shown that the greatest value of N is obtained when θ is 60°, the arch being semicircular and all the voussoirs of equal depth. When the thrust N of the opposite half-arch is exerting its greatest force upon the joint EF, it will act horizontally at the point D or vertex of the arch; and the moments of N and P about E will balance each other. We can, therefore, by the principles of mechanics (**5**) transfer them to the point E, and consider them as acting there with their original values and parallel to their original directions.

The forces which are now acting on the pier, are P the weight of the arch between EF and CD (fig. 21), together with its superincumbent load FDKL; the force $N = P\frac{x}{y}$, acting horizontally at E; the weight F of the portion HMBEFL acting vertically through its centre of gravity; and the weight Q of the pier MSTB, also acting vertically through its centre of gravity. Equating the moments of P, F and Q taken about S, to that of N, we shall obtain the thickness (t) which must be given to the pier in order that all the forces may be in equilibrium. But to secure the stability of the structure we must multiply N by the co-efficient of stability, which we may safely take as 2. We have then to determine t from the equation

Fig. 21.



$$2\,N \,.\, b = P \,.\, a + F \,.\, c + Q \,.\, q \quad . \quad . \quad (A)$$

The following are the values of each of these four quantities in the semicircular arch one foot in width of soffit.

Let δ be the weight per cubic foot of the arch and its surcharge, δ_1 that of the pier; r the radius or half-span, h the depth of the voussoirs, k the height of surcharge DK; H the height of the pier from the base S to the springing AB, t its thickness ST.

$$N \cdot b = \delta \frac{2H + r}{2h + r} \left\{ \frac{3k}{8}(r^2 - h^2) + \cdot 0257\, r^3 + \frac{3h}{8} r^2 - \frac{3h^2}{16} r - \frac{h^3}{4} \right\}$$

$$P \cdot a = \delta(\cdot 134\, r + t) \left\{ \cdot 866\, k(r + h) + \cdot 6495\, (r + h)^2 - \cdot 5236\, r^2 \right\}$$

$$F \cdot c = \delta \left\{ \frac{t^2}{2}(r + h + k) + t(\cdot 0887\, r^2 - \cdot 3h \cdot r + \cdot 134\, k \cdot r - \cdot 65\, h^2 - \cdot 866\, h \cdot k) + \cdot 00525\, r^3 - \cdot 0491\, h \cdot r^2 + \cdot 00895\, k \cdot r^2 + \cdot 1005\, h^2 r - \cdot 116\, h \cdot k \cdot r + \cdot 375\, k \cdot h^2 + \cdot 25\, h^3 \right\}$$

$$Q \cdot q = \frac{\delta_1}{2} H \cdot t^2$$

When the pier is of the same material as the arch, the quantities δ and δ_1 can be omitted altogether. If the thrust N acting at E is required, we obtain its value from

$$N = \frac{2\delta}{2h + r} \left\{ \tfrac{3}{8} k(r^2 - h^2) + \cdot 0257\, r^3 + \tfrac{3}{8} r^2 \cdot h - \frac{3h^2}{16} r - \frac{h^3}{4} \right\}$$

These formulæ appear rather complicated, but they are easy of application, and a little practice will enable anyone who has a very moderate acquaintance with algebra to calculate them readily.

Example.—Let $r = 10$, $h = 2$, $k = 5$, $H = 10$, $\delta = \delta_1 = 120$ lbs. The value of N for an arch of one foot of width of soffit and of the above dimension is 4648·8 lbs acting horizontally at E.

$$2\,N\,.\,b = 1162{\cdot}2,\ P\,.\,a = 124{\cdot}78 + 93{\cdot}128\,t.$$
$$F\,c\,. = 8{\cdot}5\,t^2 - 1{\cdot}7\,t + 1{\cdot}825,\ Q\,.\,q = 5\,t^2.$$

And the equation (A) therefore becomes

$$13{\cdot}5\,t^2 + 91{\cdot}428\,t - 1035{\cdot}6 = 0$$
$$\therefore\ t = 5{\cdot}97 \text{ feet.}$$

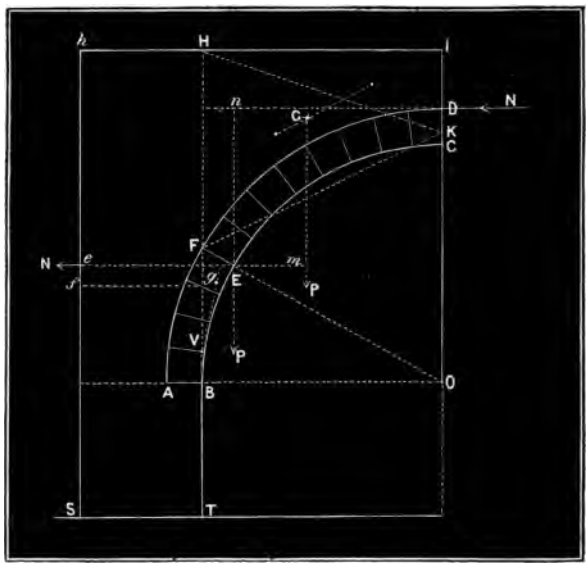
In any other semicircular arch of any span, but of which the several proportions are the same as in the foregoing example, the thickness of the pier can be determined by multiplying the radius or half span by ·597. If the height of the pier in this example is 100 instead of 10, the value of t must be 10·94; and in any other similar structure of like proportions, the thickness of the pier can be found by multiplying the radius by 1·094. In arches of different span but having the several parts in the *same proportion*, the thrust N varies as the *square* of the span; so that if the span is doubled the thrust is increased fourfold.

If in the last example we make $k = 8$, and $H = 20$, then the value of t is found to be 4·68, or nearly one-fourth the span of the arch. From this we obtain a general rule, that if the height of the pier to the springing of the arch, and the height from the springing line to the top of the surcharge, are each equal to the span of the arch, then the thickness of the abutments should equal one-fourth the span of the arch.

16. The thrust of an arch and the requisite thickness of pier may be obtained approximately by the following

geometrical process, published by the present writer in 'The Builder' for December 28, 1867. Let there be first drawn carefully to scale a section of the arch with its pier and surcharge, as in fig. 22.

Fig. 22.



We must now find the position of G, the centre of gravity of the portion HFECI, which can be done very nearly by taking CK = $\frac{1}{3}$ CD and joining FK; then the trapezium HFKI will have its centre of gravity corresponding very nearly with the point G, and its position is found by the method given in (6) fig. 9, by dividing the trapezium into two triangles by the line HK. We have then P acting at G, and its moment about E is P × E*m*; N acting at D has a moment about E of N × E*n* (E*m* and E*n* being measured by scale). Therefore

$N = P \frac{Em}{En}$; P being represented by the area of the trapezium, namely, $\frac{HF + IK}{2} \times HI$.

The force Q we may take as the area of the whole figure HS acting at its centre of gravity, and F as that of a triangle VFE also acting at its centre of gravity (g) determined as shown in (6). The forces N and P are to be considered as acting at E, and we have now to take the moments of P, F and Q about S, and equate them to twice the moment of N taken about S; we thus obtain a quadratic equation from which to find t, the thickness of the pier. The moment of N is N × Se; the moment of P is P × Ee; the moment of F is F × gf; and that of Q is HT × $\frac{t^2}{2}$. The application of this method is best shown by an example. Let OB = 10, AB = $\frac{3}{2}$, ID = $\frac{5}{2}$, BT = 10; then we find by measurement that HF = 8·17, IK = 3·5, HI = 10, Em = 3, En = 6·5, Se = 15, Ee = t + 1·33, fg = t + ·44, VF = 4. Therefore

$$P = \frac{HF + IK}{2} \times HI = \frac{8{\cdot}17 + 3{\cdot}5}{2} \times 10 = 58{\cdot}35$$

$$N = P \frac{Em}{En} = 58{\cdot}35 \times \frac{3}{6{\cdot}5} = 27.$$

To find the actual value of N for an arch of one foot length of soffit, or the horizontal thrust at E, we must multiply the above value by the weight of one cubic foot of the material used in the structure; and if that

is 120 lbs., the horizontal thrust of the arch at E will be 27 × 120 or 3240 lbs.

We can now form the moments of the forces about S;

$$2\,\mathrm{N}\,.\,b = 54 \times 15 = 810.$$

$$\mathrm{P} \times \mathrm{E}e = 58{\cdot}35\,(t + 1{\cdot}33) = 58{\cdot}35\,t + 77{\cdot}8,$$

$$\mathrm{F} \times fg = \frac{4 \times 1{\cdot}33}{2}(t + {\cdot}44) = 2{\cdot}66\,t + 1{\cdot}17,$$

$$\mathrm{Q}\frac{t}{2} = \mathrm{HT}\frac{t^2}{2} = 12t^2.$$

The equation for determining the value of t is formed by putting the first of these quantities equal to all the rest, which gives,

$$810 = 12\,t^2 + 61{\cdot}01\,t + 78{\cdot}87,$$
$$\text{or, } t^2 + 5{\cdot}1\,t - 61 = 0,$$

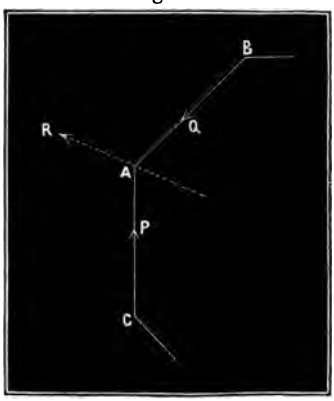
from which we obtain $t = 5{\cdot}65$.

The foregoing method will also enable us to determine whether a given thickness of pier (t) will suffice to secure the stability of an arch of known dimensions. In the last example, let us suppose 5 feet to be the given value of t, then we must put 5 for t in all the quantities which contain t, and see whether their sum is less or greater than 810, which is the value of $2\,\mathrm{N}\,b$; if it is less, then 5 is too little, and if greater, it is more than enough. When $t = 5$, $\mathrm{P} \times \mathrm{E}e = 369{\cdot}55$, $\mathrm{F} \times fg = 14{\cdot}47$, $\frac{\mathrm{Q}\,t}{2} = 300$; the sum of these is 684, which being less than 810, the structure will lack stability. If we take $t = 6$, then we find their sum is 877, which being more than 810, the structure will possess ample

stability. We can thus by trials of two or three values of t find the thickness that will ensure stability, without having to solve a quadratic equation.

17. When several arches of equal size are arranged in a straight line and supported on piers their thrusts will balance each other, so that the piers need not be of the strength which we have been finding by formulæ, but only sufficiently strong to support the superincumbent load acting vertically upon them; and it is only necessary that the end piers or abutments shall be of the strength given by the rules. When, however, the arches are arranged round a circle or polygon instead of in a straight line, the case is different, there being an outward thrust which is not counterbalanced by the mutual reactions. For example, suppose we have eight arches arranged in the form of an octagon on plan and supported only upon light piers; let AB (fig. 23) represent one side of the octagon, AC an adjoining side; P the horizontal thrust of the arch AC, Q that of the arch AB; the forces P and Q being equal will, by the principles of mechanics (**2**), have a resultant R whose direction bisects the angle BAC. The tendency therefore of the forces P and Q is to thrust out A in the direction, AR; and we must therefore have a counterbalancing force equal to R acting towards A in the direction of RA, in order that

Fig. 23.



the forces may be in equilibrium. From (**2**) we at once find the relation which R must bear to P and Q;

$$\text{for, } R : P :: \sin. QAP : \sin. RAQ,$$
$$\text{or, } R : P :: \sin. 45° : \sin. 67°\tfrac{1}{2}$$
$$:: 101 : 132$$

so that $$R = P \times \frac{101}{132}.$$

Example:—Let eight arches be arranged in the form of an octagon, each being of the form and dimensions of the example in (**16**). Let the soffit of the arches be 2 feet wide, then P and Q is each 2 × 3240 or 6480 lbs.

Therefore $$R = 6480 \frac{101}{132} = 4958 \text{ lbs.}$$

The force R may be the thrust of another arch placed in the direction AR; and if this arch has the same proportions as the other arches, we can at once determine its span, since the thrusts of similar arches are to one another as the squares of their spans. Now the span of the arches forming the octagon being 20 feet, we find,

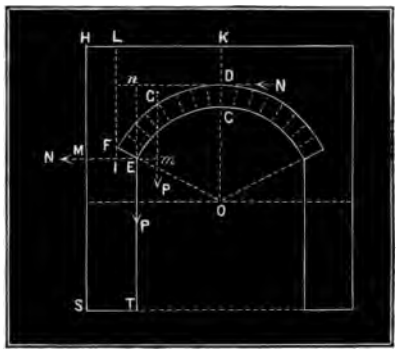
$$\text{span of arch in AR} = 20 \sqrt{\frac{R}{P}} = 20 \sqrt{\frac{101}{132}}$$
$$= 17{\cdot}5 \text{ feet.}$$

No allowance is here made for the resistance offered by the pier, which is supposed to be only of sufficient strength to bear the vertical weight of the superstructure.

18. SEGMENTAL ARCH.—The thrust of segmenta

arches, and the requisite thickness of pier, may be determined in the same manner as in semicircular arches, with such modifications as the particular case may demand. Let us take an arch whose form is that of a segment of a circle, subtending 120° at the centre, as in fig. 24. The weakest joint will be at the springing EF, since FEO makes 60° with the vertical; the values of P and N will be the same as in the semicircular arch (**15**) and will act at E; N will act in the direction EM, and P in that of ET. The force F we can now consider as the area of the parallelogram HMIL, (neglecting the small wedge EFI). Then the moments of the forces about S are

Fig. 24.



$$P \times EM = P \,.\, t;\ N \times ET = P \frac{Em}{En} ET;$$

$$F \times \frac{MI}{2} = HM \frac{MI^2}{2};\ Q \frac{t}{2} = ET \frac{EM^2}{2} = ET \frac{t^2}{2}.$$

Putting ET = H, and the other dimensions as in (**15**) we have

$$N \times ET = \delta \frac{2H}{2h + r} \left\{ \frac{3k}{8} (r^2 - h^2) + \cdot 0257 r^3 + \frac{3h}{8} r^2 - \frac{3h^2}{16} r - \frac{h^3}{4} \right\}$$

$$P \,.\, t = \delta t \left\{ \cdot 866k (r + h) + \cdot 6495 (r + h)^2 - \cdot 5236 r^2 \right\}$$

$$F \times \frac{MI}{2} = \delta . HM \times \frac{MI^2}{2} = \frac{\delta}{2}\left(\frac{r}{2} + h + k\right)(t - \cdot 866h)^2$$

$$Q \times \frac{t}{2} = \delta_1 . ET \times \frac{t^2}{2} = \frac{\delta_1}{2} H . t^2.$$

Then the value of t is determined as before, by equating twice the moment of N to the sum of the three other moments. The span in this arch will be $1 \cdot 732r$.

Let us apply it to an arch having the dimensions of the example in (**15**). The actual value of N for an arch having a soffit 1 foot wide is, as before, 4648·8 lbs.

Also $2N \times ET = 774 \cdot 8$; $Pt = 93 \cdot 128t$; $F \times \frac{MI}{2}$ $= 6t^2 - 20 \cdot 784t + 18$; $Q\frac{t}{2} = 5t^2$; and the equation becomes

$$774 \cdot 8 = 11t^2 + 72 \cdot 344t + 18$$

which reduces to

$$t^2 + 6 \cdot 58t - 68 \cdot 8 = 0;$$

therefore $t = 5 \cdot 63$ ft.

The span of this arch is 17·32 feet. In any other segmental arch of similar proportions, the thickness of pier will be $\cdot 563r$.

We will now take the case of a segmental arch which subtends an angle of 90° at the centre O. The weakest joint will be at the springing as before, but the joint EF being now nearer the crown, the thrust N is less than in the semicircular arch of same radius. The value of N acting horizontally at E for an arch whose soffit is 1 foot in width is,

$$N = \frac{\delta}{h + \cdot 293r}\{\cdot 0116r^3 + \cdot 25(h + k)r^2 - \cdot 073h^2 r - \cdot 132h^3 - \cdot 25kh^2\}$$

and the moment of N about S is N × H. Also,

$$P \times ST = \delta . t\{\cdot 707k(r + h) + \cdot 457(r + h)^2 - \cdot 393r^2\}$$

$$F \times \frac{MI}{2} = \frac{\delta}{2}(\cdot 293r + h + k)(t - \cdot 707h)^2$$

$$Q \times \frac{t}{2} = \frac{\delta_1}{2} H . t^2.$$

The span of this arch is $1 \cdot 414r$.

As an example of this form of arch, we will find the thrust and thickness of pier when the other dimensions are the same as in the last example.

The value of N for an arch having a soffit 1 foot wide and of material weighing 120 lbs. to the cubic foot, is 4324 lbs., which is the horizontal thrust at E. Then supposing the whole structure to be built of the same material, and therefore omitting the weight from the calculations, we have twice the moment of N about S equals 720·6;

$$P . t = 68 \cdot 93t; \quad F \times \frac{MI}{2} = 4 \cdot 965t^2 - 14 \cdot 04t + 9 \cdot 93;$$

$$Q\frac{t}{2} = 5t^2. \quad \text{The equation is}$$

$$720 \cdot 6 = 9 \cdot 965t^2 + 54 \cdot 89t + 9 \cdot 93;$$

or,
$$t^2 + 5 \cdot 5t - 71 \cdot 3 = 0;$$

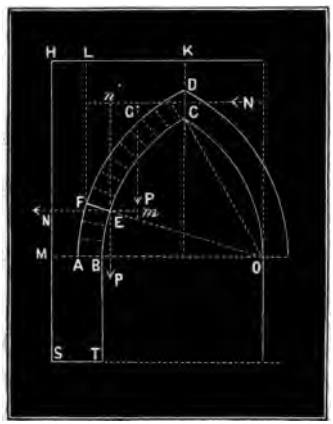
$$\therefore \ t = 6 \cdot 15 \text{ feet.}$$

The span in this case is 14·14 ft. In any other segmental arch of the same form and proportions, the thickness of pier must be $\cdot 615r$.

If in this last example, we make the height H of the pier 100 feet instead of 10 feet, its thickness must be 11 feet; and in the like proportion for any other height between 10 and 100 feet.

19. GOTHIC ARCH.—The thrust of Gothic or pointed arches (fig. 25) can be calculated in the same manner as described for semicircular arches, only the position of EF, the weakest point, has to be determined for each particular case separately, as it varies according to the *pitch* of the arch. Thus in the equilateral arch, in which OC makes 30° with the vertical, the joint FE makes the angle 16° with the horizontal; in an arch in which OC makes 15° with the vertical, EF makes 28° with the horizontal; and when OC makes 45° with the vertical, EF makes 10° with the horizontal. The equilateral arch may be taken as a good representation of the general forms of large 'Gothic' arches. In this case we suppose N to act at the middle of the joint CD, its moment about E being N × E*n* which equals P × E*m*; P being, as before, the weight of the portion LFECK acting at G its centre of gravity. Also F is the weight of the part HLFEBM acting at its centre of gravity; Q the weight of the pier MBTS. Then the value of N acting horizontally at E is found to be in the equilateral arch,

Fig. 25.



$$N = \frac{\delta}{\cdot 59r + \cdot 56h}\Big\{k\,(\cdot 1064r^2 - \cdot 462h^2) + \cdot 0134r^3 + \cdot 123r^2 \,.\, h - \cdot 273h^2 \,.\, r - \cdot 449h^3\Big\}.$$

If this is multiplied by the height SN, or b, we have $N.b$ the moment of N about S. In this case $b = H + \cdot 276r$. The moments of P, F and Q about S are

$$P \,.\, a = \delta\,(\cdot 039r + t)\,\{k\,(\cdot 4613r + \cdot 96h) + \cdot 0995r^2 + 1\cdot 1h \,.\, r + \cdot 9775h^2\}$$

$$Q.q = \frac{\delta_1}{2} H \,.\, t^2$$

$$F.c = \delta\{t^2\,(\cdot 5k + \cdot 433r + \cdot 58h) + t\,(\cdot 0264r^2 + \cdot 039k \,.\, r - \cdot 523h \,.\, r - \cdot 98h^2 - \cdot 96h \,.\, k) + k\,(\cdot 0075r^2 - \cdot 037h \,.\, r + \cdot 46h^2) + \cdot 0063r^3 + r \,.\, h\,(\cdot 235h - \cdot 0133r) + \cdot 45h^3\}.$$

These are readily calculated by putting for r, h, k and H, their respective values; r = OB, h = EF or AB, k = DK, H = MS. We then find t from the equation,

$$2\,N \,.\, b = P \,.\, a + F \,.\, c + Q \,.\, q.$$

Example:—Let $r = 10$, $h = 1$, $k = 4$, $H = 10$, $\delta = \delta_1 = 120$. Then, omitting the value of δ and δ_1 we have $2N \,.\, b = 249\cdot 6$; $P \,.\, a = 44\cdot 22t + 16\cdot 11$; $F \,.\, c = 6\cdot 91t^2 - 5\cdot 85t + 11\cdot 13$; $Q \,.\, q = 5t^2$. Therefore the equation is,

$$249\cdot 6 = 11\cdot 91t^2 - 38\cdot 37t + 27\cdot 24;$$

$$\text{or, } t^2 + 3\cdot 22t - 18\cdot 7 = 0;$$

$$\therefore\ t = 3 \text{ feet.}$$

The horizontal thrust of N at E in this arch for every foot width of soffit is 1174 lbs. In any arch of similar proportions the thickness of the pier must be

three-tenths of the span. If we increase the height of the pier to 100 feet, or ten times the span, the thickness of pier must be 5·46 feet, or ·546*r*. The investigation of the thrust of Gothic arches was published by the present writer in 'The Builder,' March 31, 1866.

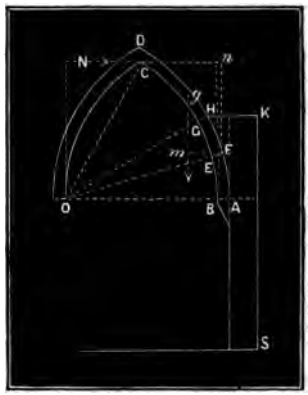
20. ELLIPTIC ARCH.—The horizontal thrust of an elliptical arch can be found from that of a semicircular one; being very nearly the same as that of a semicircular arch, having the same span, but whose vertical depth is to that of the elliptical arch as the major to the minor axis of the ellipse. (Fenwick's 'Mechanics of Construction.') Thus, if the height of the ellipse is 20 feet to a span of 60 feet, the axes being in the proportion of 3 to 2; then if the voussoirs at the crown are 2 feet deep, the equivalent circular arch will have a radius of 30 feet, and depth of voussoirs 3 feet. This is only an approximation, and the exact relations between the several parts may be investigated directly in the same manner as given for the circular arch; but the algebraical formulæ are more complicated, and the position of the weakest joint must be determined in each particular case. In an ellipse, however, which is not very flat, the weakest joint may be taken as very nearly that which makes 30° with the horizontal, as in the circular arch.

21. GOTHIC VAULTING consists of a number of stone arched ribs which spring from the walls of a building, or from corbels projecting therefrom; the space between the ribs being filled in with stone panelling of a light character. To avoid complicating the question of thrust in such arches, we will suppose the vaulting to

consist of transverse ribs whose direction is at right angles to the walls, and diagonal ribs making 30° with

Fig. 26.

Fig. 27.



the former, as in the plan, fig. 26. The transverse rib (fig. 27) we will suppose to be an equilateral arch. We will omit from the investigation all intermediate ribs and filling in, which is made as light as possible, and can be allowed for by adding something to the thickness of the main ribs themselves. The back of the ribs is filled up to the haunches as far as HM, so as to prevent them from yielding at that part; OH making 30° with the horizontal. In this kind of arch, having no surcharge, there is a tendency to break up by the rising of the crown and the falling in of the haunches; so that the joint CD will tend to open at D, and the weakest joint EF to open at E; the portion above EF tending to turn over on the point F. We shall here take EF as making 16° with the horizontal as in (**19**). The horizontal thrust N at the crown will now act through C, and its moment about F will equal that of P about F; P being the weight of the part above EF

acting at the centre of gravity. Let l be the breadth of soffit of each rib, h the depth of the ribs, r the radius OB, δ the weight per cubic foot. Then the value of N is found to be

$$N = \frac{l \cdot \delta}{\cdot 59r - \cdot 28h}\{\cdot 0003r^3 + \cdot 1487h \cdot r^2 + \cdot 651h^2 \cdot r + \cdot 402h^3\}.$$

The moment of N about S, the outer edge of the base of the pier, is $N \cdot b$; where $b = H + \cdot 276\,(r + h)$; H being the height of the pier to the springing AB. Also if we put P, the weight of the portion above EF, acting in this case at F, R that of the part MFEBA, acting vertically through its centre of gravity, their moments about S are

$$P \cdot a = l \cdot \delta\,(\cdot 0387\,(r + h) + t)\{\cdot 0095r^2 + \cdot 787h \cdot r + \cdot 68h^2\}$$

$$R \cdot c = l \cdot \delta\{t(\cdot 0122r^2 + \cdot 304h \cdot r + \cdot 152h^2) + \cdot 0002r^3 + \cdot 00424h \cdot r^2 + \cdot 144h^2 \cdot r + \cdot 048h^3\}.$$

The diagonal ribs will not have the same pitch as the transverse ones, but we may, without materially affecting the calculations, treat them as equilateral, having for their radius $1 \cdot 155r$. The thrust of these ribs will be oblique, so that we must only take the resolved part of the horizontal thrust N′ perpendicular to the wall, multiplying by cos. 30°, or ·866. The value of N′ acting perpendicularly to the wall for each diagonal rib is

$$N' = \frac{l \cdot \delta}{\cdot 787r - \cdot 319h}\{\cdot 000463r^3 + \cdot 1985h \cdot r^2 + \cdot 75h^2 \cdot r + \cdot 402h^3\}.$$

r being the radius of the *transverse* rib. Then the moment of N′ about S is N′. b', where $b' = \mathrm{H} + \cdot 318r + \cdot 276h$. Also we find,

$$\mathrm{P}'.\ a' = l\ .\ \delta(\cdot 039r + \cdot 034h + t)\ \{\cdot 0127r^2 + \cdot 909h + \cdot 68h^2\}.$$

$$\mathrm{R}'.\ c' = l\ .\ \delta\ \{\ t\ (\cdot 0128r^2 + \cdot 348h\ .\ r + \cdot 152h^2) + + \cdot 00021r^3 + h\ .\ r\ (\cdot 00477\ r + \cdot 144h) + \cdot 042h^3\}.$$

We will take the width ab (fig. 26) of the pier as $3l$; then we have

$$\mathrm{Q}\ .\ q = \frac{3\ l\ .\ \delta_1}{2}\left(\mathrm{H} + \tfrac{1}{2}\ (r + h)\right) t^2.$$

The equation from which t is found is $2\mathrm{N}\ .\ b + 4\mathrm{N}'\ .\ b' = \mathrm{P}\ .\ a + 2\ \mathrm{P}'\ .\ a' + \mathrm{Q}\ .\ q + \mathrm{R}\ .\ c + 2\mathrm{R}'\ c'$.

Example:—$r = 20, h = 1, l = \frac{1}{2}, \mathrm{H} = 30, \delta = \delta_1 = 120$. The horizontal thrust of the transverse rib at F is found to be 196 lbs.; that of the two diagonals resolved perpendicular to the wall is 380 lbs.; or the total thrust at F is 576 lbs. The thickness (t) of the pier is found by the formulæ:

$2\ \mathrm{N}\ .\ b = 233{\cdot}34$; $4\ \mathrm{N}'.\ b' = 465$;

$\mathrm{P}\ .\ a = 8{\cdot}22 + 10{\cdot}11\ t$; $2\mathrm{P}'.\ a' = 19{\cdot}16 + 23{\cdot}8t$:

$\mathrm{R}\ .\ c = 3{\cdot}15 + 5{\cdot}56t$; $2\mathrm{R}'.\ c' = 6{\cdot}5 + 12{\cdot}2t$;

$\mathrm{Q}\ .\ q = 30{\cdot}37t^2$. And the equation becomes

$$698{\cdot}34 = 30{\cdot}37t^2 + 51{\cdot}77t + 37{\cdot}03;$$

or,
$$t^2 + 1{\cdot}7t - 21{\cdot}77 = 0;$$

$$\therefore\ t = 3{\cdot}89 \text{ feet.}$$

In any other vaulting of the same proportions t is found by multiplying the *half-span* by ·389. If the value of H is 60ft., the value of t must be 4·365 feet.

The foregoing investigations are taken from a paper by the present writer published in 'The Builder,' July 21, 1866.

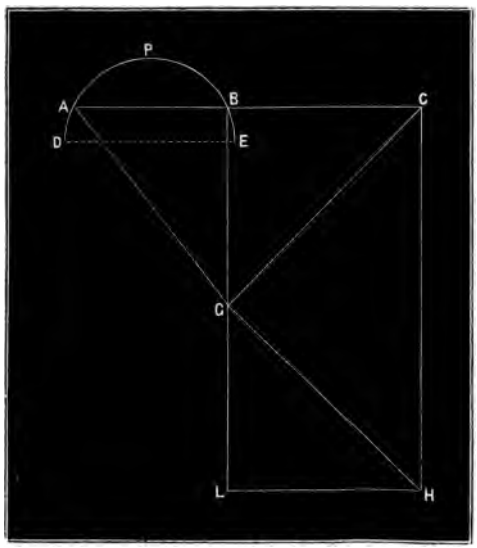
22. OBLIQUE ARCH.—When two roads at different levels cross each other in directions which are not at right angles to each other, and an arch is thrown across the lower road to carry the upper one, it is called an 'oblique' or 'skew' arch; and the angle which a perpendicular to the axis of the lower road makes with the axis of the upper one is called the 'angle of obliquity.' If the courses of an *oblique* arch were built so as to be at right angles to the abutments, as in the ordinary arch, a large part of them would have no abutment at one side, and the arch would fail. If, on the other hand, the beds of the courses were parallel to the two faces of the arch, they would abut obliquely on the piers, and the soffit would not form an even surface.

This last plan has occasionally been adopted in small arches of moderate obliquity, but would be very deficient in stability if used for large arches, or where the obliquity was considerable. The method adopted in large oblique arches is to consider the arch as a portion of two concentric cylinders cut obliquely by the two planes forming its faces, and which are parallel to the direction of the upper roadway. The solid contained between these two cylinders is cut by a number of screw surfaces all of similar form and described about a common axis; and these again are intersected at right angles by another set of screw surfaces, also of similar form. In this way the solid contained between the two cylinders is divided into a number of equal and

similar solids which are the voussoirs of the arch. The templates for forming these voussoirs require to be made with considerable accuracy, the several angles being calculated by the help of trigonometry for each particular case. The rules for getting out the templates are given in Buck's 'Treatise on Oblique Arches,' to the last edition of which Mr. Barlow has added a method of arriving at the necessary results without the actual use of trigonometrical formulæ. A small work by Mr. W. Donaldson also gives a very accurate method. Oblique arches should always be segments of circles of considerable flatness, and the obliquity may be made with safety as great as 65°.

In fig. 28, DEP represents the semicircle of which

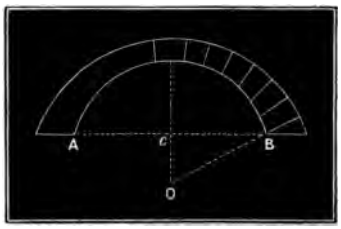
Fig. 28.



APB is the segment employed as the section of the

soffit of the oblique arch. Let BAG be the angle of obliquity; BC the length of the arc APB developed, and drawn perpendicular to BG. Then GC is the spiral of the heading joints, and is to be divided into the determined number of voussoirs. To this the direction of the coursing joints is to be perpendicular. Make GH perpendicular to GC, and CH parallel to BG; draw HL perpendicular to CH; then GH is the development of the segmental spiral, and GL its axial length. The lines of the faces of the arch are ellipses, and the joints of the voussoirs all radiate from a point O (fig. 29) situated below the springing line or axis of the cylinder; its position being found by calculation.

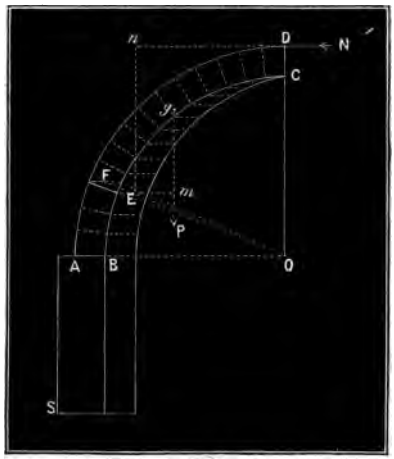
Fig. 29.



23. CUPOLAS.—If we suppose an arch of any form of section to revolve about its vertical axis, a hollow shell will be formed, which is called a 'cupola' or 'dome.' Such a shell is often built over a circular chamber, either underground or above ground. When built underground, it possesses great strength and power of resistance to pressure, having all the rigidity of the vertical and horizontal arch combined, and any thrust is entirely overcome by the surrounding earth. The dome is built on the principle of the arch, having wedge-shaped voussoirs; but as it consists of a series of horizontal rather than vertical arches, it follows that as soon as any number of courses are completed the structure is in a condition of stability, and requires no

further support from centering except for the construction of the remaining courses; so that any number of the upper courses may be omitted without endangering its stability. When a dome is elevated upon a circular wall or 'drum,' it will produce a certain horizontal thrust upon the wall. The investigation of the thrust and necessary thickness of wall may be made in the same manner as that adopted in the case of the ordinary arch; by considering the dome to consist of a number of small ribs or slices cut out of the entire dome by two planes intersecting at the vertical axis, and making a small angle, as 2°, with each other. Fig. 30 represents a rib cut out of one side of a circular dome, which for the sake of investigation we may consider as balanced by an equal rib cut out of the opposite side; the two ribs meeting at the crown C D, and balancing each other by their mutual pressures, which we call N, acting horizontally. Of course such ribs could not be built to stand alone, but the lateral pressure of the whole circle of ribs keeps them together. The horizontal thrust of a dome upon the walls is much less than would arise from an ordinary arch of equal span; and it may be reduced still further by means of iron belts girding the dome at a short distance above the

Fig. 30.



springing. The weakest joint of the hemispherical dome is ascertained, by analytical methods, to be that which makes 20° with the horizontal; it is therefore at this point that the iron belt will produce the greatest effect in counteracting the thrust. Using the same notation as in the arch, we have P the weight of the part above the weakest joint EF; F that of the part below EF; Q that of the portion of the wall or *drum* on which the rib stands; N the horizontal thrust. Having determined the position of the weakest joint EF, we can suppose P and N to act at E; F at the centre of gravity of the part between EF and AB; Q at the centre of gravity of the pier. Let R and r be the external and internal radii of the dome; δ the weight of a cubic foot of the dome; δ_1 that of the pier. Then the thrust N at E of the 180th part of the dome is found to be,

$$N = \delta \frac{\cdot 00719r\,(R^3 - r^3) - \cdot 00393\,(R^4 - r^4)}{R - \cdot 34202r}.$$

Hence it appears that in domes of similar proportions the horizontal thrust varies as the *cube* of the diameter or span.

The moment of N about the outer edge of the pier is N . b, where $b = H + \cdot 34202r$; H being the height of the pier to the springing of the dome.

The moments of the other forces about the outer edge of the base of pier are

$$P \,.\, a = \cdot 00766\,\delta\,(R^3 - r^3)\,t + \cdot 00046\,\delta(R^3 - r^3)r,$$

$$F \,.\, c = \cdot 00398\,\delta\,(R^3 - r^3)\,t + \cdot 00398\,\delta\,\{r(R^3 - r^3) - \cdot 735\,(R^4 - r^4)\},$$

$$Q \,.\, q = \cdot 00582\,\delta_1\,(3rt^2\ t^3)\ H.$$

The value of t, or the thickness of the pier sufficient for stability, is found from the equation,

$$2\,N\,.\,b = P\,.\,a + F\,.\,c + Q\,.\,q.$$

Example. — Let $r = 10$, $R = 11$, $\delta = 125$ lbs., $\delta_1 = 150$ lbs., $H = 50$ ft. Then we find

$$2\,Nb = 9830;\ P\,.\,a = 316{\cdot}8t + 191{\cdot}1;$$
$$F\,.\,c = 164{\cdot}7t - 50{\cdot}5;\ Q\,.\,q = 1309t^2 + 43{\cdot}6t^3.$$

And the equation reduces to

$$t^3 + 30t^2 + 11t - 222 = 0;$$

the solution of which is easily obtained by Horner's process (see 'De Morgan's Arithmetic'), and is found to be $t = 2{\cdot}45$ ft.

The value of N in this case is 92 lbs., which is the horizontal thrust at E of the 180th part of the dome. In any hemispherical dome whose thickness is one-tenth of the radius, and the height of the pier five times the radius, the thickness of the pier is $\cdot 245r$. When H is 10 ft., t is found to be 2·07 ft.; and when H is 100 ft, t is 2·8 ft. The dome in this case is supposed to be of uniform thickness throughout, and the wall or pier of solid construction.

When the section of the dome is a Gothic or pointed arch, the position of the weakest joint will depend on the *pitch* of the arch; if the *pitch* is low or the section differs but little from a semicircle, the weakest joint will make an angle of nearly 20° with the horizontal, but if the *pitch* is high, it makes a much smaller angle. Thus, for instance, if the radius drawn to the vertex

makes only 10° with the vertical, the weakest joint makes 17° with the horizontal; but when that radius makes 22½° with the vertical, the weakest joint makes 13½° with the horizontal; and if it is at 30° with the vertical, then the weakest joint is 10° only with the horizontal. The value of N, or the horizontal thrust at E, diminishes as the pitch increases; so that, if in the hemisphere it is 92, in the Gothic domes of the three sections above described it is 88·7, 80·4, and 77·3 respectively, the *span* being the same in all. In a parabolic dome of the same span as the above, the height being equal to half the span, the thrust is 79·6, and acts at the springing, which is the weakest joint. If the thickness of the hemispherical dome is made to diminish upwards, so as to be half the thickness at the crown, that it is at the springing, the thrust is greatly decreased, being only 55·8 in the dome of 20 ft. span, as compared with 92 in the dome of uniform thickness. The foregoing description is taken from two papers by the present writer on the 'Stability of Domes,' read before the Royal Society, May 31 and November 22, 1866, and published in the 'Proceedings of the Royal Society,' No. 85, and also in the 'Civil Engineer and Architect's Journal' for February and March, 1868.

CHAPTER IV

BUILDING STONES.

24. THE stones used for structural purposes in this country are divided into five distinct classes, namely: 1, Granites; 2, Sandstones; 3, Limestones; 4, Oolites; 5, Magnesian Limestones.

GRANITES are classed by geologists among what are termed 'metamorphic' rocks, having been originally deposited in a very different condition to that in which they are now found. They possess a more or less crystalline character, which has been produced by long-continued chemical action combined with great heat and pressure, by which their original nature has been entirely transformed. Granites differ considerably in the qualities of durability, hardness and crushing strength, some being readily disintegrated by the action of weather, while others possess great durability, and may be safely employed to resist the constant wearing effects of water. Their resistance also to crushing varies very greatly, specimen of Cornish granite having been crushed with a weight of 6,400 lbs. per square inch, while others from Peterhead and Aberdeen have required a pressure of 8,300 lbs. and 10,900 lbs.

per square inch to crush them. The specific gravity of granite varies from 2·6 to 2·9; and the weight per cubic foot from 162 lbs. to 180 lbs.

The component parts of granite are quartz, feldspar, and mica or talc. These are *mechanically* united in various proportions, each of the three being a distinct mineral composed of bodies which are *chemically* united. Quartz is pure crystallized silica or silicic-acid, and is the hardest of all the substances found in the composition of rocks; and the durability of stone mainly depends on the proportion of silica which it contains, it being perfectly insoluble in water or weak acids, although it is soluble in powerful alkalies. Feldspar is the mineral which gives the variety of colour to granites, the colour being chiefly owing to the greater or less proportion it contains of the per-oxide (rust) of iron. In 100 parts of feldspar, 65 are generally silica, 18 alumina, which is the basis of clays, and 16 potash. Granites, which contain a large proportion of feldspar, are not suited for building purposes, as this material is the first component which is decomposed by the action of weather or of dilute acids, and is converted thereby into a soft friable mass of earthy matter. Mica consists of thin transparent plates of great hardness, and to it is due the glittering appearance observable in granite. It contains 40 to 50 per cent. of silica, 16 to 37 per cent. of alumina, 7½ to 10 per cent. of potash, and a considerable proportion of the peroxide of iron.

Granite lies at the bottom of the strata forming the crust of the earth, but from the action of subterranean

forces it has been lifted up, so that it forms the substance of some of the highest mountains.

25. SANDSTONES are so called from being chiefly composed of sandy or siliceous particles, which are cemented together by a small proportion of carbonate of lime. They all contain more or less of the peroxide of iron, to which material their variety of colour is owing; the red and brown sandstones containing as much as three per cent. of iron, while in the light-coloured stones only a slight trace is to be found. Sandstones also vary greatly in quality, some being soft and easily reduced to powder, whilst others are among the hardest of the rocks. They also belong to nearly all the main divisions of the geological crust of the earth; those found in the lower or more ancient strata being harder, heavier, and more durable than those found in the higher or more recent strata. Thus, for example, in this country we have sandstones in the 'Chalk' formation which weigh only 103 lbs. to 111 lbs. per cubic foot, and these are generally of a soft and friable nature. Others are found in the 'Wealden,' which underlies the 'Chalk,' weighing 118 lbs. per cubic foot. In the 'Lias,' which is below the 'Wealden,' we find sandstones weighing 127 lbs. per cubic foot. In the 'New Red Sandstone' series which underlies the 'Lias,' there are sandstones, such as that of Mansfield, weighing 146 lbs. to the cubic foot, and having a crushing strength of 5,000 lbs. per square inch. The Mansfield stone forms in its chemical composition a connecting link between the sandstones proper and the magnesian limestones, being found to

contain 49 per cent. of silica, 26½ per cent. of carbonate of lime and 16 per cent. of carbonate of magnesia. The red stone is found to be less durable than the white. By far the largest number, as well as the most useful, of the sandstones are found in the 'Carboniferous' series, which underlies the 'New Red Sandstone;' for although this series derives its name from the presence of layers of coal, yet the principal proportion of it consists of sandstone rocks, varying greatly in texture and character, but known generally by geologists as the 'grits.' They are all more or less laminated, which enables us in most cases to detect readily the natural bed of the stone; some are so highly so that they split up with a slight blow into thin slabs or 'flags,' and are then only fit for paving purposes. The 'grits' are generally very durable *when laid on their natural bed*, but if laid with their bed vertical they will flake off like the leaves of a book, when exposed to the action of the atmosphere. Their weight varies from 140 lbs. to 160 lbs. per cubic foot, and the crushing strength from 4,000 to 8,000 lbs per square inch. They contain from 93 to 98 per cent. of silica, with only a very small quantity of carbonate of lime; hence they are valuable stones for buildings which are exposed to a smoky or damp atmosphere, as dilute acids do not injure them.

The formation next below the 'Carboniferous' in geological sequence, and known as the 'Old Red Sandstone,' contains many varieties of sandstones suitable for building purposes, some of which are highly durable, while others, which contain a considerable

proportion of iron, are found to decompose rapidly. They are heavy stones, weighing from 150 lbs. to 160 lbs. per cubic foot.

26. LIMESTONES are so called from being chiefly composed of the carbonate of lime, and are found more or less in nearly all the geological strata. They vary greatly in texture, some having the softness of chalk, and others a hardness equal to that of granite. Those which are not fit for use as building stones are valuable for burning into lime. The weight of the freestones which can be used for building is from 130 to 150 lbs. per cubic foot, and the crushing strength from 2,000 lbs. to 6,000 lbs. per square inch. The Chilmark stone (Wilts) has a crushing strength of 6,395 lbs. per square inch, and contains 10½ per cent. of silica, 79 per cent. of carbonate of lime, 3·7 per cent. of carbonate of magnesia. It weighs 151 lbs. per cubic foot.

27. The OOLITES, which form a large and very useful class of building stones, are limestones of a peculiar construction, being composed of small particles, like the *roe* of a fish, cemented together. They contain little or no silica, being almost entirely composed of carbonate of lime with a small proportion of the carbonate of magnesia. The best of those found in this country is from the Island of Portland, which contains 1·2 per cent. of silica, 95 per cent. of carbonate of lime, and 1·2 per cent. of carbonate of magnesia. Its crushing strength is 3,900 lbs. per square inch, and its weight varies from 132 lbs. to 136 lbs. per cubic foot. Bath stone contain no silica, but has 94½ per cent. of

carbonate of lime, and 2½ per cent. of carbonate of magnesia. The crushing strength of that from the Box quarries is 1,492 lbs. per square inch, and its weight is 123 lbs. per cubic foot. The Ancaster stone has a similar composition to the Bath, but is harder and heavier, its crushing strength being 2,345 lbs. per square inch, and its weight 139 lbs. to the cubic foot. The oolitic series lies geologically between the Chalk and the New Red Sandstone.

28. The MAGNESIAN LIMESTONE derives its name from being composed of the carbonates of lime and magnesia in nearly equal proportions. It belongs geologically to the New Red Sandstone series. The texture is very irregular, and it is consequently not to be always depended upon as a good *weather* stone; that which is most crystalline is the best for resisting the action of weather. The stone from Bolsover is the hardest and most compact found in this country, its crushing strength being 8,300 lbs. per square inch, and its weight 152 lbs. per cubic foot. It contains 3·6 per cent. of silica, 51 per cent. of carbonate of lime, and 40 per cent. of carbonate of magnesia; its specific gravity is 2·3. The weight of that from the Anston quarries is 144 lbs. per cubic foot.

29. POROSITY.—A very important feature to be considered in selecting stone for the outside walls of buildings is the amount of water which it will absorb when exposed to the action of driving rains. A large number of specimens of various kinds of stone, well dried, were left for several days in water, and being carefully weighed both before and after the saturation,

the exact quantity of water absorbed was ascertained. Among sandstones, we find that specimens of Cragleith stone and from Park Spring (Yorkshire) absorb ·08 of their bulk of water; Kenton stone, ·099 of its bulk; Heddon stone ·104 of its bulk; Mansfield white, ·092; and Mansfield red, ·104. Morley Moor stone (Derbyshire) absorbs ·134 of its bulk; Redgate stone (Durham) absorbs ·104 of its bulk.

Among the magnesian limestones, the Bolsover stone absorbs ·079 of its bulk of water; Jackdaw Craig, ·104 of its bulk; Huddlestone, ·12; Roach Abbey stone, ·172; Park Nook, ·221; Cadeby, ·256. Of the limestones which are not oolitic, the Chilmark absorbs from ·028 to ·086 of its bulk of water; Hamhill, ·115; Barnack, ·141.

Of the oolites, Portland stone absorbs ·135 of its bulk of water; Ketton, ·151; Ancaster, ·166; Box (Bath), ·169; Haydor (Lincoln), ·207.

For full information respecting the building stones of this country the reader is referred to the report of the Commissioners on Stone for Building the Houses of Parliament, most of which is reprinted in Gwilt's 'Encyclopædia.' Also to the mineral statistics of the United Kingdom in the 'Memoirs of the Geological Survey of Great Britain,' edited by R. Hunt, 1860, in which there is a short notice of all the important quarries in the kingdom.

30. MORTAR is the material used for causing the beds of stones and bricks of which a wall is built to adhere together, so as to form one solid mass. It is composed of lime and sand intimately mixed together

with water. The lime is obtained by burning limestone in a kiln, by which means the water and carbonic acid in combination with the lime is driven off and 'quick' lime is obtained. When water is added to quick-lime it is rapidly absorbed, great heat being given out at the same time; the lime then becomes the hydrate of lime and is said to be 'slacked;' it then gradually absorbs carbonic acid from the atmosphere, and returns to its old condition of carbonate of lime, and, in conjunction with the sand, forms a siliceous limestone. Mortars that harden slowly should be protected from the weather for some time, as rain-water easily dissolves the hydrate of lime if exposed to its action before it has had time to become a carbonate.

Cements are artificial compounds of lime, iron, silica or sand, and alumina; they do not require any admixture with sand, which only weakens them. When mixed with water they set rapidly, and become very hard in a few hours.

31. In order to protect the face of stones which are much exposed to weather or the action of acids, various processes have been devised. Ransome's method is to coat the stone with a thin film of silicate of lime, which is done by first washing the surface with a solution of silicate of soda, obtained by boiling flints in a solution of caustic soda. The surface is then played upon with a solution of the chloride of calcium, obtained by dissolving lime in muriatic acid; a chemical change immediately takes place, the silicate of soda changing to silicate of lime, which is insoluble in water, and the chloride of calcium changing to

chloride of sodium or common salt, which is very soluble in water, and is easily washed off.

Ransome's concrete stone is prepared in a similar manner. Finely sifted dry sand is mixed with a small proportion of pulverised stone or carbonate of lime, to each bushel of which mixture is added one gallon of the liquid silicate of soda, and the whole is well mixed in a mill. The plastic mass thus obtained is put into moulds and well rammed with wooden instruments so as to fill up all the interstices. When turned out of the moulds the blocks are played upon with a cold solution of the chloride of calcium, by which the mass is quickly solidified. It is then immersed in a boiling solution of the same material, and when removed from the bath is washed with water to remove the salt deposited on the surface.

The crushing strength of this material varies according to the nature of the substances used in its composition.

32. When large flat stones, in which the area of the beds is great in proportion to the thickness, are subjected to heavy pressure, it is necessary to be very careful in making the beds perfectly even; otherwise, if there is any projection in the bed, it becomes a fulcrum for the superincumbent weight to break the stone upon, it being then subjected to a transverse strain instead of a simple crushing weight. It is in consequence of neglecting this precaution that large stones are so frequently fractured, the resistance of stones to transverse strain being much less than their resistance to crushing.

CHAPTER V.

TIMBER.

33. GROWTH.—The various timbers used for the purposes of building are derived from the class of trees which botanists denominate 'Exogens' or outward growers, the new wood being added to the *outside* of that formed during the previous year. All trees found in cold climates and also the greater part of those in the tropics, belong to this class. The mode of development is as follows: the first year's growth of the stem consists of a central part called the *Pith*, which is surrounded by a woody stem, covered on the outside by the *Bark*. In the second year the inner part of the bark separates from the wood, and sap forms between the wood and the bark, the new sap wood being connected with the pith by means of cross passages called medullary rays, through which the secretions pass from the outside to the centre. The root absorbs juices from the soil and conveys them to the woody fibres immediately surrounding the pith, by which they pass upwards and throughout all the branches to the leaves. By means of the leaves the superfluous water is given off, and the fluid entirely changes its nature. It now descends through a series

of tubes in the inner part of the bark, and is deposited so as to form the new wood, bark, &c. The circulation of the sap will continue in trees after the *outer* part of the bark has been removed. The *pith* connects the root with the leaf-buds, to which it conveys nourishment; it is at first green, and filled with fluid, but loses its colour as it dries up when the tree gets old; this is the first part that decays in the live tree, the *dead knots* found in wood being the dried up pith of the branches, and many trees which appear sound outside will, when cut up, be found partly decayed in the middle. The cellular mass of the stem is pressed into plates of various thickness by the wedges of wood formed within it, so that when a transverse section is made of the stem these plates appear as a number of lines radiating from the centre, and are called the medullary rays. The medullary sheath consists of spiral vessels surrounding the pith, projections of which pass through it into the medullary rays; by means of this sheath oxygen is conveyed to the leaves, being obtained by the decomposition of water or of carbonic acid. Surrounding this sheath is the *wood* proper, which consists of concentric layers formed by successive deposits year after year of the nutriment which descends from the leaves. In countries which have a winter and summer, each layer of wood is the produce of one year's growth; the secretions are found most abundant in the oldest layers, and when these become filled up they cease to perform any vital function, and form what is termed *heart wood.* The bark also consists of concentric layers, being increased by additions to

its inner layers so as to allow for the gradual distension of the wood beneath ; the outer bark does not increase but splits off, and a new one takes its place. The bark serves the double purpose of being a protection to the new wood, and also a filter through which the descending juices pass. Full information on the growth of trees will be found in Rhind's ' History of the Vegetable Kingdom,' and other works on scientific botany.

34. DECAY.—When timber has been employed in a building, it is sometimes found, after a few years, to be in a state of decay, so that the safety of the whole structure becomes endangered. This generally arises from the use of new timber insufficiently seasoned. When a tree is fresh cut down it contains a considerable amount of moisture, especially in the part near the outside called the *sap-wood.* Before, therefore, being used in a building it should be well seasoned, so as to get as much as possible of the sap out of it ; if this is not done a certain amount of fermentation will take place inside the timber, which causes the deposition of the spores of fungi upon it, as these are constantly floating in the air unperceived, and only waiting for a situation suitable to their development in order to deposit themselves. If the timber is in a damp place without ventilation or a free current of air, the fungi develop very rapidly into minute fibres, covering the whole surface of the wood with a white film ; these fibres penetrate into all parts of the wood, from which they suck the juices and soon leave nothing but a soft, dry, powdery mass, which will fall to pieces when touched. A free current of air is hostile to the growth

of the fungi, while a stagnant condition of the air, especially if the temperature is high, accelerates their growth. If sap-wood is used in a building, it is always the first to be affected by decay.

35. STRENGTH OF TIMBER.—It is shown by writers on the 'strength of materials' that when a beam is fixed or supported in a horizontal position and strained by a force (W), the 'moment of resistance' of the beam at any section is directly as the *moment of inertia* (**12**) of the section, taken about its *neutral axis* (**10**), and inversely as the distance of the neutral axis from the farthest edge of the section.

When a rectangular beam AB is fixed in a wall at A (fig. 12)* and strained by a weight W at the other end B, the *moment of the strain* at any point D (where BD = x) was shown in (**8**) to be

$$M = W . x,$$

which must equal the *moment of resistance*, namely,

$$M = S\frac{I}{z},$$

where I is the moment of inertia of the section, z the distance of the neutral axis from its furthest edge, S a constant depending on the nature of the material. The section of the beam being a rectangle of depth d and breadth b, we have by (**12**), $I = \frac{1}{12} b . d^3$, and $z = \frac{1}{2}d$.

Hence it follows that

$$W . x = \frac{1}{6} S . bd^2.$$

* Page 14.

The strain is of course greatest when $x = l$, the length of the beam, in which case we have

$$W = \tfrac{1}{6} S \frac{bd^2}{l} \quad . \quad . \quad (A).$$

When the weight W is uniformly distributed over the entire length of the beam, we have from (8) for the moment of strain at A,

$$M = \frac{W}{2} l = \tfrac{1}{6} S . bd^2,$$

$$\therefore W = \tfrac{1}{3} S \frac{bd^2}{l} \quad . \quad . \quad (B).$$

When the beam is supported at each end and loaded at the distance a from one end and b from the other, it was shown in (8) that $M = W \frac{a . b}{l}$, therefore in this case

$$W = \tfrac{1}{6} S \frac{b . d^2}{a . b} l \quad . \quad . \quad (C).$$

If the load is in the middle, $a = b = \frac{1}{2} l$, and

$$W = \tfrac{2}{3} S \frac{bd^2}{l} \quad . \quad . \quad (D).$$

When the beam is uniformly loaded throughout, we have, by (8), $M = \frac{1}{8} W l$, and therefore

$$W = \tfrac{4}{3} S \frac{bd^2}{l}. \quad . \quad . \quad (E).$$

The value of S has to be determined by experiment, for each kind of material. For if a beam, supported at each end, breaks with a load W at the middle, the value of S can be obtained from the equation,

$$S = \tfrac{3}{2} W \frac{l}{b . d^2} .$$

Experiments by Barlow* on beams of the best English oak, 7 ft. long and 2 in. square, give W = 637 lbs. as the breaking weight in the middle. Substituting these values in the formula for S, we have,

$$S = \tfrac{3}{2} \times 637 \times \frac{84}{2 \times 4} = 10{,}033.$$

In order to find the strength of any other beam of oak, we have only to substitute this value of S in either of the foregoing formulæ, (A), (B), (C), (D), (E).

In a similar manner the value of S may be obtained from the experiments of Barlow upon other kinds of timber, as given in the table below, all the dimensions being put into inches in using the formulæ, and the breaking weight W in pounds.

	Value of S
Red pine	8,046
Pitch „	9,792
Riga fir	6,477
Beech	9,336
Oak, British	10,032
„ Dantzic	8,742
„ Canadian . . .	10,600

From the above formulæ it will be seen that the breaking weight at the weakest part of a rectangular beam is proportional to the breadth multiplied by the square of the depth, divided by the length. Also, by comparing (D) and (E), it appears that when the weight is equally distributed over the whole length of the beam, the breaking weight is twice as great as when concentrated at the centre. Hence we may consider the beam's own weight as straining it with a force equal to that produced by half its weight laid on the centre,

* Barlow, *On Strength of Material.* Lockwood & Co. 1869.

and the beam may then be considered as without weight.

It is found by experiment that when the ends of a beam are firmly fixed in a wall, the breaking weight is half as much more as when the ends are only supported loosely.

The permanent load laid upon a beam of timber ought not to exceed one-sixth of the breaking weight.

Example.—Let a beam A B (fig. 15)* of English oak, having a breadth 8 in., depth 10 in., and length 120 in., be loaded at D, 40 in. from A and 80 in. from B; to find the breaking weight. By formula (C) we have,

$$W = \tfrac{1}{6} S \frac{b d^2}{a b} l = \frac{10032}{6} \times \frac{8 \times 100}{40 \times 80} \times 120 = 50160 \text{ lbs.}$$

If D is the centre of the beam, by formula (D) we have,

$$W = \tfrac{2}{3} S \frac{b d^2}{l} = 6688 \times \frac{800}{120} \quad 44587 \text{ lbs.}$$

Let the same beam be laid on its side; then we have $b = 10$ in., $d = 8$ in., and the breaking weight is,

$$W' = 6688 \times \frac{640}{120} = 35669 \text{ lbs.}$$

so that $W' : W :: 640 : 800$, or as $4 : 5$. This difference arises from the fact of the strength being proportional to the *square* of the depth, while it is only as the first power of the breadth. If, then, we double the breadth we double the strength, but by doubling the depth we quadruple the strength.

* Page 17.

If a prop or pillar is placed under the centre of a beam, supported at each end, it then becomes divided into two separate beams, each of which being half the length will have double the strength of the unsupported beam, since the strength is inversely as the length; so that the whole beam will bear four times as much when supported in the middle as well as at the ends, as it will when only supported at the ends; and one-half the load will be borne by the pillar.

36. DEFLEXION.—A beam that is supported or fixed in a horizontal position, and subjected to a transverse strain, will be bent or deflected from the straight line, and will assume a curved form. The resistance to deflexion follows a very different law to the resistance to fracture. Let D be the amount of deflexion or distance of the centre of a loaded beam (supported at each end) from its position when unloaded; E the *modulus of elasticity* (**11**); W the load laid on at the centre; l the distance between the points of support; b the breadth and d the depth of the beam. Then it is shown by writers on the strength of materials, that when the *limit of elasticity* is not exceeded, the deflexion varies *directly* as the weight W and as the *cube* of the depth d; it is also *inversely* as the *moment of inertia* (I) of the section. Hence we obtain the expression for the deflexion,

$$D = \frac{W}{48E} \times \frac{l^3}{I}.$$

And in a rectangular beam, $I = \frac{1}{12} b \cdot d^3$ (**12**),

$$\therefore D = \frac{W}{4E} \times \frac{l^3}{b \cdot d^3}.$$

The *resistance* to deflexion is, of course, *inversely* as the deflexion, and is expressed by the formula,

$$\frac{1}{D} = \frac{4E}{W} \times \frac{b \cdot d^3}{l^3}.$$

That is to say, the *resistance to deflexion* is directly as the breadth into the cube of the depth, and inversely as the load into the cube of the length.

The value of E is found from the equation,

$$E = \frac{W}{4D} \times \frac{l^3}{b \cdot d^3}.$$

In the case of an oak beam 2 in. square and 84 in. long, supported at the ends and loaded with 200 lbs. in the middle, a deflexion of 1·28 was obtained. Substituting these values in the formula for E, we get,

$$E = \frac{200}{4 \times 1{\cdot}28} \times \frac{84^3}{2 \times 2^3} = 1447031.$$

In a similar manner we obtain the values of E from experiments on other kinds of timber, as given in the following table:—

	Value of E
Red pine . . .	1,840,000
Pitch „ . . .	1,225,000
Riga fir	1,285,700
Beech	1,353,000
Oak, British . . .	1,447,000
„ Dantzic . . .	1,165,000
„ Canadian . . .	1,893,000

The formula for deflexion shows us the advantage gained by increasing the depth; for if we have two beams of equal length and breadth, but the depth of one beam double that of the other, the deflexions with the same load will be as 1 to 8, or by doubling the

depth we increase the power of resisting flexure eight times.

When the load is uniformly distributed over the whole length of the beam, it can be demonstrated that the deflexion is reduced to five-eighths of what it is when the load is concentrated at the middle; so that the deflexion of a beam, arising from its own weight alone, is five-eighths of that which it would have if all its weight was supposed to act at its centre. The deflexion of a beam, whose ends are firmly fixed, is half that of the same beam when the ends are loosely supported.

Example 1.—To find the deflexion of the oak beam in (**35**) with W equal to one-fourth of the breaking weight laid on the middle. Here,

$$D = \frac{W}{4E} \times \frac{l^3}{b.d^3} = \frac{11147}{4 \times 1447000} \times \frac{120^3}{8000} = \cdot 416 \text{ in.}$$

If the beam is laid on its side and loaded with one-fourth of its breaking weight, we find D = ·512 in.

Example 2.—Let it be required to find the breadth that must be given to an oak beam 10 in. deep and 10 ft. bearing, in order that its deflexion shall not exceed one-tenth of an inch when loaded in the middle with a weight of 2,240 lbs. Here we have to calculate b from the equation,

$$b = \frac{W.l^3}{4E.D.d^3} = \frac{2240 \times 1728000}{578800 \times 1000} = 6 \cdot 68 \text{ in.}$$

Now, suppose the breadth to be given, say 8 in., and it

is required to find the depth. We have to calculate the value of d from the equation,

$$d^3 = \frac{W.l^3}{4E.D.b} = \frac{2240 \times 1728000}{578800 \times 8} = 836.$$

$$\therefore d = \sqrt[3]{836} = 9{\cdot}42 \text{ in.}$$

37. PILLARS.—When timber is subjected to a compressing force in the direction of its length, as when used for columns, struts, &c., it will break either by bending, or by the crushing of its fibres, or by a combination of bending and crushing. This will depend on its length as compared with its diameter; for if its length is 30 times the diameter, the pillar will break by bending before crushing can begin. If its length is less than 25 times, but more than 10 times the diameter, it will break partly by crushing and partly by bending. If the length is less than 10 times the diameter, it will break by crushing only.

From Hodgkinson's experiments, it appears that for long pillars of wood the breaking-weight is as the fourth power of the diameter divided by the square of the length; or

$$W = a \times \frac{d^4}{l^2}.$$

The value of a is 24542 for Dantzic oak, and 17511 for red deal, W being in lbs., d in inches, and l in feet. In practice a pillar ought not to be loaded with more than one-tenth of its breaking-weight; so that if we put 2454 and 1751 for a, the above formula will give us the *safe permanent load.*

Example.—Let $l = 10$ ft., $d = 4$ in., $a = 2454$; then

$$W = 2454 \frac{4^4}{10^2} = 6{,}282 \text{ lbs., safe load.}$$

Mr. Hodgkinson found by experiment that if the load does not press on the pillars exactly in the direction of its axis, the strength is greatly diminished; and if it act in the direction of the diagonal, the strength is reduced to one-third of what it is when it acts down the axis.

When the length of a pillar is less than 25 times its diameter, but more than 10 times, the resistance to *crushing* comes into action as well as the resistance to *bending*, the material being partly crushed before it breaks by bending. Mr. Hodgkinson's method of approximating to the strength of such pillars is, first to calculate the breaking-weight (b) by the formula for long pillars, as above; then if c is the area of the section of the pillar in inches multiplied by the crushing strength per square inch (as per table),* the breaking-weight (W) is found by the formula,

$$W = \frac{b \cdot c}{b + \frac{3}{4}c}.$$

Thus, in deal the crushing strength per square inch is 6,000 lbs. to 7,000 lbs., and in oak 10,000 lbs. Let us find, for example, the breaking-weight (W) of a pillar of oak, 4 in. square, whose length is 5 ft., or 15 times the diameter; then we have,

$$b = a \frac{d^4}{l^2} = 24542 \times \frac{256}{25} = 251{,}314 \text{ lbs.}$$

$$c = 16 \times 10{,}000 = 160{,}000.$$

* Page 77.

$$\therefore W = \frac{251{,}314 \times 160{,}000}{251{,}314 + 120{,}000} = 108{,}292 \text{ lbs.}$$

The *permanent safe load*, acting in the direction of the axis of the column, will therefore be 10,829 lbs.

38. In pillars whose length is less than 10 diameters, the material is crushed before it can begin to bend, and therefore the crushing strength alone has to be considered, which is in proportion to the area of the transverse section; so that the strength of a short pillar is found by multiplying the number of square inches in the section by one of the numbers in the following table, which is the result of Hodgkinson's experiments on cylinders of wood, 1 in. diameter and 2 in. long, flat at the ends. The figures in the first column are for specimens moderately dry, while those in the second column are for specimens kept in a warm place for two months longer, after being turned. It was found that wet timber showed great weakness, being in some cases less than half as strong as dry timber. (See Mr. Hodgkinson's paper in the 'Phil. Trans.,' 1840.)

In making use, however, of this table, it must be borne in mind that when a piece of timber is cut out of a tree, different parts of it will possess different degrees of strength. Thus the older wood near the centre will be much harder and stronger than that near the outside; the strength will also depend upon the age of the tree, older trees which have not begun to decay being generally tougher than younger ones. For these reasons the tabulated numbers can only be taken as giving an approximation to the relative strength of different kinds of wood.

Description of Wood.	Crushing strength per square inch in lbs.	
Alder	6,831	6,960
Ash	8,683	9,363
Baywood	7,518	7,518
Beech	7,733	9,363
Birch (American)	—	11,663
„ (English)	3,297	6,402
Cedar	5,674	5,863
Crab	6,499	7,148
Deal (Red)	5,748	6,586
„ (White)	6,781	7,293
Elder	7,451	9,973
Elm	—	10,331
Fir (spruce)	6,499	6,819
Hornbeam	4,533	7,289
Larch (fallen 2 months)	3,201	5,568
Mahogany	8,198	8,198
Oak (Quebec)	4,231	5,982
„ (English)	6,484	10,058
„ (Dantzic, very dry)	—	7,731
Pines, pitch	6,790	6,790
„ yellow, full of turpentine	5,375	5,445
„ red	5,395	7,518
Plum (wet)	3,654	—
„ (dry)	8,241	10,493
Poplar	3,107	5,124
Sycamore	7,082	—
Teak	—	12,101
Walnut	6,063	7,227
Willow	2,898	6,128

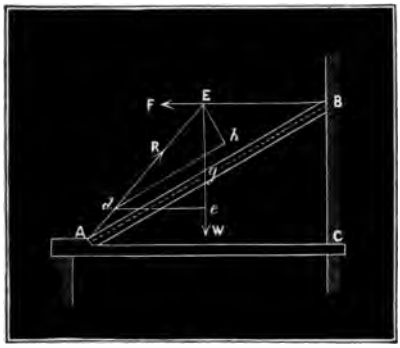
39. The resistance of timber to a stretching force acting in the direction of its length is proportional to the area of the transverse section, and quite independent of the length. The *ultimate strength*, or force, that will break timber by stretching, is 12,000 lbs. per square inch for fir, and 15,000 lbs. for oak. Therefore to find the resistance of any piece of fir or oak to a stretching force, multiply the number of square inches in its section by either of the above numbers.

40. Timber Framing.—When a piece of timber is

used in framework, it is subjected to one or more of the strains which we have been considering, and its proportions must be arranged according to the amount, character, and direction of the strains it has to bear. When a beam is subjected to a strain in any direction, the straining force can be resolved into two forces, one acting transversely and another acting longitudinally, by means of the principle of the resolution of forces (**2**).

Suppose a rafter AB (fig. 31) carrying a load W acting at its centre of gravity *g*, to lean against a wall at B, and to be framed into a horizontal beam at A. Let F be the reaction of the wall acting horizontally at B; then R the reaction at A is the resultant of the two forces W and F, and its direction meets that of W and F in E. If then E*e* is taken to represent on scale the weight W, the horizontal line *de* will represent F, and E*d* will represent R, in direction and magnitude; or the three forces W, F and R are in the ratio of the three sides of the triangle E*ed*.

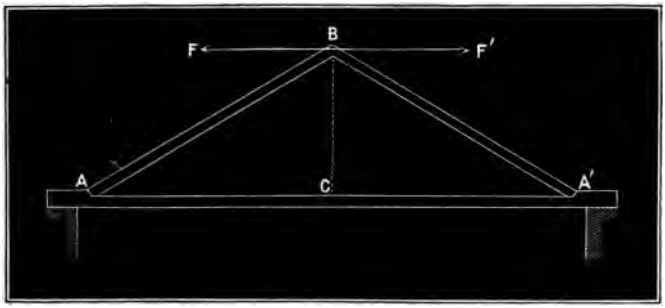
Fig. 31.



Now, suppose the wall BC removed, and that in its place is substituted another rafter BA′ equal to AB, and framed into the tie-beam AA′ (fig. 32); F will now be the mutual pressure of the two rafters at B, and the horizontal strain on the tie-beam will be re-

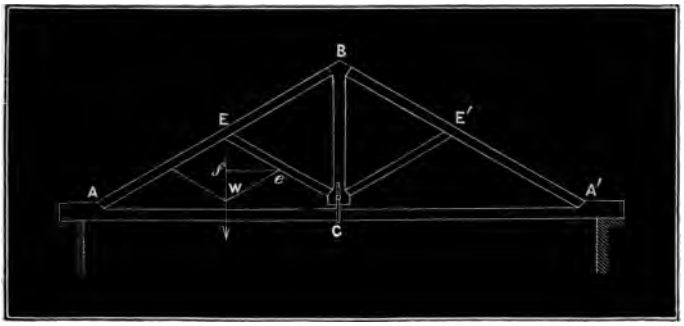
presented by the line *de* (fig. 31); E*e* being the line which represents the weight laid on each rafter. The

Fig. 32.



tie-beam must also be made sufficiently strong to bear its own weight without bending, which it may also be prevented from doing by being held up in the middle by a piece of timber called a king-post, into the head of which the two rafters are framed (fig. 33); by this

Fig. 33.

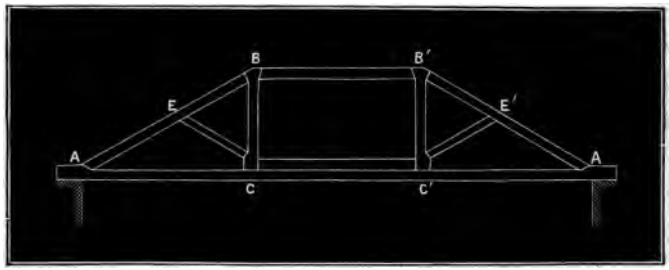


means the transverse strain on the tie-beam is reduced to one-fourth of what it is when the king-post is absent, so that its dimensions may be reduced accordingly; the vertical strain on the king-post is *half* the weight of the tie-beam.

The next step is to strengthen the rafters by means of struts CE and CE′ framed into the foot of the king-post, and supporting the centre of each rafter. The pressure at E of the load on the rafter may be considered as *half* the entire load laid on the rafter. Let EW represent the vertical load at E; draw W*e* parallel to AB and *ef* horizontal. Then E*e* represents the compression on the strut, which can be resolved into its vertical and horizontal components E*f* and *ef*, the former of which represents the *additional* vertical strain produced by *each* strut on the king-post; and the latter is counterbalanced by the horizontal thrust arising from the opposite strut CE′.

The tie-beam may be sustained in two places by means of queen-posts AB, A′B′ (fig. 34), into the

Fig. 34.



heads of which the rafters are framed, and their reaction transmitted by the straining-piece BB′, which is *compressed* by the force F, represented by *de* (fig. 31). Each queen-post sustains one-fourth the weight of the tie-beam, and the tie-beam will be able to bear nine times as great a transverse strain as it would if supported only at the ends. Each queen-post has to

sustain the vertical component of the thrust from *one* of the struts, the horizontal components being counterbalanced by means of a straining-piece inserted between the feet of the queen-posts.

To find the strains upon the rafter AB (fig. 31), resolve the resultant R into its two components perpendicular and parallel to AB; these will be represented by the lines E*h* and *dh*; then E*h* represents the transverse strain at the centre, and *dh* the longitudinal compression.

41. In order to be able to determine the dimensions that must be given to the timbers of a roof, we must know what weight it will have to carry. Tredgold gives the weight of a slated roof with the timbers as 26 lbs. per square foot of surface, to which he adds 40 lbs. per foot for the action of 'wind and other occasional forces;' this is probably sufficient to allow for the pressure of the wind on a roof of moderate pitch; but as recent experiments have shown that the force of a high wind sometimes amounts to 55 lbs. per square foot on a plane surface exposed to its direct action, we must add as much as this where the roof is of high pitch. For low-pitched roofs we may therefore consider 66 lbs. per foot as the total pressure to be sustained, and in roofs of high pitch 80 lbs. per foot must be taken as the load.

The following rules are given by Tredgold for determining the scantlings of the several timbers of a trussed roof of *fir*. Let *b* be the breadth in inches, *d* the depth in inches, and *l* the length in feet of any beam :—

1. King-post, $b \times d = \cdot 12\ l \times s$ = area of section, where s is the span in feet.

2. Queen-post, $b \times d = \cdot 27\ l \times s$ = area of section, where s is the length of the part of the tie-beam which each post sustains in feet.

3. Tie-beam; s being the length in feet of the longest unsupported part; $d = 1 \cdot 47 \frac{s}{\sqrt[3]{b}}$, in inches.

4. Principal rafters having a king-post; $d = \cdot 96 \times \frac{l^2 \times s}{b^3}$, in inches, s being the span in feet. When there are two queens, the multiplier is ·155 instead of ·96.

5. Straining-beam between heads of queen-posts, where $d : b = 10 : 7$, or $b = \cdot 7\ d$; then $d = \cdot 9\sqrt{l\sqrt{s}}$; s being the span in feet.

6. Struts and braces supporting rafters, of which s is the length unsupported in feet; where $d : b = 10 : 6$, or $b = \cdot 6\ d$; then $d = \cdot 8\sqrt{b\sqrt{s}}$.

7. Purlins; s being their distance apart in feet, where $b = \cdot 6\ d$; then $d = \sqrt[4]{s.l^3}$.

8. Common rafters, where l is the bearing in feet, $d = \cdot 72 \frac{l}{\sqrt[3]{b}}$.

42. CENTERINGS for arches are structures of timber, temporarily erected for the purpose of sustaining the voussoirs until the arch is completed and is able to sustain itself. On account of the friction of their surfaces, the voussoirs do not begin to press upon the centering until the joints make an angle of 30° with the horizontal; the pressure then increases slowly up

to 45°, when it amounts to one-fourth the entire weight of the voussoir. After the angle of 45° is passed the pressure of each stone increases more rapidly, being at 60° rather more than half the weight of the voussoir. After this the stones soon press with their whole weight on the centering; and any voussoir in which a vertical line dropt from its centre of gravity, falls outside its lower joint, may be considered as pressing with its full weight on the centering. This variation in the pressures of the stones upon the centering is the chief matter to be considered in designing a centre, as greater strength and support must be given to the parts near the crown than to those at the haunches. The laying of the voussoirs must also be proceeded with uniformly on both sides of the arch after the angle of 30° is passed, so as to prevent the frame-work from being distorted by unequal pressure on the two sides.

CHAPTER VI.

IRON.

43. IRON is employed for structural purposes, under three different forms, namely:—(1) Cast-iron; (2) Wrought-iron; (3) Steel.

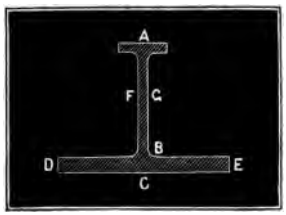
Cast-iron contains from $2\frac{1}{2}$ to 5 per cent. of carbon, and is manufactured by pouring the molten metal into moulds; it is brittle and readily broken by a sudden blow, the fracture generally presenting a crystalline appearance; its brittleness is increased by the addition of carbon. It also flies into fragments if cold water is applied to it when in a heated state; hence its use must be avoided in buildings intended to resist the action of fire, or where it would be subjected to sudden jars or changes of load.

The crushing strength of cast-iron being six times as great as the resistance to bending, it becomes a valuable material for columns which have to sustain a vertical pressure.

When beams are formed of cast-iron they require to be carefully tested before being fixed, as this material is liable to flaws from carelessness in the casting, or from being allowed to cool too rapidly, whereby it becomes honeycombed in the middle. The strongest

form of cast-iron beam of given weight and depth was determined by Hodgkinson, after numerous experiments, to be that in which the top and bottom flanges are to one another in the inverse proportion of the resistance to bending to the resistance to crushing, or as six to one; since the top is subjected to compression while the bottom is subjected to extension. The section of the beam in the centre is that of (fig. 35), two-thirds of the metal being contained in the lower flange.

Fig. 35.



An approximate rule for the strength of such a beam is,

$$W = 26\frac{A \cdot d}{l} = \text{breaking-weight in tons at the centre;}$$

where A is the area of the section of bottom flange in the middle, d to the total depth AC of the beam, l the span; all the dimensions being in inches. This rule is formed on the supposition that the strength of the flanges is so great that the resistance of the middle part is small in comparison, and may be neglected.* As an example, let $A = 4{\cdot}4$, $d = 5\frac{1}{8} = \frac{41}{8}$, $l = 54$; then

$$W = \frac{4{\cdot}4 \times 41}{8 \times 54} = 10{\cdot}86 \text{ tons.}$$

The permanent load on a cast-iron beam should never exceed one-sixth of the breaking weight.

Another approximate rule for the strength of such a beam is given by Hodgkinson, in which the effect of

* Hodgkinson, *On Cast Iron.*

the vertical part or web is taken into consideration, and the operation of the top flange of a beam, when strained, is supposed to be that of a fulcrum on which to break the bottom flange and web. Putting d for the total depth AC, d_1 for the depth AB to the top of the lower flange, b the breadth DE of lower flange, b' the thickness FG of the web (all in inches), and l being the length of bearing in feet, the breaking-weight in the centre, in tons, is

$$W = \frac{2}{3\,d\,.\,l}\left\{b\,.\,d^3 - (b - b')\,d_1^3\right\}.$$

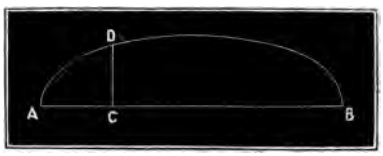
This formula depends on two suppositions: 1st, that all the particles, except those in the top flange of a bent beam, are in a state of tension; 2nd, that the resistance of each particle is as its distance from the top of the beam.

When the depth of a cast-iron beam is uniform throughout, it would be a great waste of metal to have the lower flange of the same width at the ends as at the middle, and in order to obtain a beam of uniform strength at every part, the plan of the lower flange should be in form of a double parabola, or flat segment of a circle (fig. 36); for the strength varies as the breadth $d\,e$ at any part, and also the strain is, by (8), as the product of $Ae \times Be$, and in the parabola $d\,e$ varies as $Ae \times Be$. If, on the other hand, the lower flange is kept of the same width throughout, a beam of uniform strength may be obtained by making the depth vary,

Fig. 36.

so as to form an ellipse (fig. 37); for the strength at any part is as the square of D C, and also the strain is as A C × B C, which expresses the relation between the co-ordinates of the ellipse.

Fig. 37.



44. COLUMNS.—The strength of columns of cast-iron has been largely tested by Mr. Hodgkinson, whose researches thereon are detailed in the 'Philosophical Transactions' for 1840 and 1857. The power of a column to sustain a vertical pressure depends much upon the proportion which the diameter bears to the length. When the length is 30 times the diameter, the column will only be broken by bending, and the resistance of the material to crushing will not come into play. In long hollow columns the breaking-weight in tons is,

$$W = 42 \frac{D^{3\cdot5} - d^{3\cdot5}}{l^{1\cdot63}},$$

D being the external and d the internal diameter in inches, and l the length in feet. This formula also applies to solid columns, by making $d = 0$.

In order to calculate the strength of a column by this formula, use must be made of a table of logarithms; thus, for a solid column, take out of the table the logarithm of the diameter, and multiply by 3·5; multiply the logarithm of the length by 1·63, and subtract the product from the former quantity; to the difference add the logarithm of 42, and the result is the logarithm of the breaking-weight, which will be found on refer-

ence to the logarithmic table. The following table of the values of $D^{3\cdot5}$ and $l^{1\cdot63}$ will facilitate the calculation, which can then be made without the use of logarithms,

$2^{3\cdot5} = 11\cdot3$,	$5^{1\cdot63} = 13\cdot8$,
$2\cdot5^{3\cdot5} = 24\cdot7$,	$8^{1\cdot63} = 29\cdot6$,
$3^{3\cdot5} = 46\cdot8$,	$10^{1\cdot63} = 42\cdot7$,
$4^{3\cdot5} = 128$,	$12^{1\cdot63} = 57\cdot4$,
$5^{3\cdot5} = 279$,	$15^{1\cdot63} = 82\cdot6$,
$6^{3\cdot5} = 529$,	$20^{1\cdot63} = 132$.

Example.—To find the breaking-weight of a hollow column 10 ft. long, whose external diameter is 4 in. and internal diameter 3 in., by means of the foregoing table.

$$W = 42\,\frac{4^{3\cdot5} - 3^{3\cdot5}}{10^{1\cdot63}} = 42\,\frac{128 - 46\cdot8}{42\cdot7} = 80 \text{ tons, nearly.}$$

The *constant* 42 was obtained as the mean of the experiments on thirteen specimens of different kinds of iron, in which the number varied from 33·6 to 49·9; so that by using 42, we have the value of W less than the breaking-weight for the best iron, and more than the breaking-weight for inferior qualities.

Mr. Hodgkinson found that in solid cast-iron columns of small diameter, the outside was harder and stronger than the inside; in one specimen, $2\frac{1}{2}$ in. diameter, the crushing strength of a piece cut out of the centre was found to be 29·65 tons per square inch; that of the intermediate part 34·59 tons; while the external ring, half-an-inch thick, of a hollow cylinder 4 in. diameter, of which the outer crust had been removed, had a crushing strength of 39·06 tons; and thinner rings of the

same iron had a crushing-strength of 49·2 to 51·78 tons per square inch. Hence it is advantageous to employ hollow columns as thin as practicable in preference to solid ones. He found, however, in his later experiments on *large* castings, that the difference of hardness between the external and internal parts was much less than in *small* castings, and may generally be neglected.* Also that three solid pillars, whose sections were circular, square, and triangular, and whose area of section was the same, had their strength in the proportion of

$$55299 : 51537 : 61056;$$

the triangular section giving the greatest strength, and the square one the least.

45. When the length of a column is much less than thirty diameters, the resistance to crushing comes into action before it can be broken by bending. In such columns the above formula requires to be modified in the following manner:—Let c be the crushing-strength of the section, or the area of the section multiplied by the crushing-strength per square inch, which we may put at 49 tons for hollow columns. First calculate the strength by the previous formula for long pillars, and let b be the breaking-weight thus obtained, then the true breaking-weight will be,

$$W = \frac{b \cdot c}{b + \frac{3}{4}c}.$$

Take the last example, and let the length be 5 ft. instead of 10 ft.; then we have,

* *Philosophical Transactions*, 1857.

$$b = 42\,\frac{128-46{\cdot}8}{13{\cdot}8} = 247 \text{ tons};$$

$$c = 49 \times \frac{22}{7}\,\{2^2-(\tfrac{3}{2})^2\} = 269 \text{ tons};$$

$$W = \frac{247 \times 269}{247+202} = 148 \text{ tons}.$$

When a column is less than 10 diameters in length, it may be considered as breaking only by crushing and not by bending, so that only the crushing-strength of the section has to be taken into account; this is found by multiplying the area of section by the crushing-strength of the metal per square inch, which is about 49 tons for hollow columns, and 39 tons for solid columns.

If a hollow column is not of uniform thickness of metal throughout, its real strength will be only that of the *thinnest* part.

The above formulæ are for columns without discs at top and bottom; when the ends are expanded in the form of discs so as to distribute the pressure over a greater surface, the strength is somewhat greater than that obtained by these rules.

If an iron column is not set perfectly upright it loses a considerable portion of its strength, which will also be the case if it should be thrust out of the perpendicular by any settlement of the building. When a long column is so much out of perpendicular, that the diagonal has become vertical instead of the axis, it is found to have lost two-thirds of its strength.

The permanent safe load supported by a cast-iron column must never exceed one-fourth of the breaking-weight.

46. WROUGHT-IRON.—Wrought, or malleable iron, possesses a fibrous and non-crystalline texture, and contains very little carbon, so that it is tough, and will bear heavy blows without fracture; it will bend considerably before breaking, and withstands the action of fire much better than cast-iron does; the resistance to compression is about two-thirds of the resistance to extension. Wrought-iron is not so generally used for columns as cast-iron, but for very long columns the breaking-weight is considerably more in wrought-iron than (with the same dimensions) in cast-iron; the breaking-weight being found by Hodgkinson* to be,

$$W = 134 \frac{d^{3\cdot55}}{l^2}, \text{ in tons.}$$

d being the diameter in inches, l the length in feet. A few values of $d^{3\cdot55}$ are given to assist calculation:—

$2^{3\cdot55} = 11\cdot7,$	$4^{3\cdot55} = 137\cdot2,$
$2\cdot5^{3\cdot55} = 25\cdot8,$	$5^{3\cdot55} = 303\cdot6,$
$3^{3\cdot55} = 49\cdot4,$	$6^{3\cdot55} = 578\cdot8.$

For example, to find the breaking-weight of a solid wrought-iron pillar, 4 in. diameter and 10 ft. long; here we have,

$$W = 134 \frac{4^{3\,55}}{10^2} = 134 \frac{137\cdot2}{100} = 194 \text{ tons.}$$

The breaking-weight of the same column in cast-iron is

$$W = 42 \frac{4^{3\cdot5}}{10^{1\cdot68}} = 42 \frac{128}{42\cdot7} = 126 \text{ tons.}$$

* *Philosophical Transactions*, 1840.

For short columns, in which the resistance to crushing comes into action, cast-iron has the advantage over wrought-iron. The same formula can be employed in finding the strength of wrought-iron columns whose length is less than 30 diameters, as was used for short cast pillars, only 16 tons must be taken as the crushing-strength per square inch instead of 49, as in cast-iron. If, then, b is the breaking-weight as calculated by the above formula for long pillars, c the crushing-strength of the section, or the area of section multiplied by 16, then the true breaking-weight of a short wrought-iron pillar, in tons, is

$$W = \frac{b \times c}{b + \frac{3}{4}c}.$$

Taking the last example, 5 feet long, we have

$$b = 134 \frac{137{\cdot}2}{25} = 776 \text{ tons};$$

$$c = \frac{22}{7} \times 4 \times 16 = 201;$$

$$W = \frac{776 \times 201}{776 + 150} = 168\tfrac{1}{2} \text{ tons}.$$

The strength of the same column in cast-iron is 282 tons.

47. BEAMS.—Wrought-iron is extensively employed in the construction of beams of various forms and sizes. For small beams, as joists, or light girders of moderate length, it is generally rolled in one piece, of an I or L form of section, according to requirements.

To find the strength of a rolled joist of I section, let I be the moment of inertia of the section, d its total

depth; then it is shown by writers on the strength of materials that the *moment of resistance* at any section is

$$M = S \frac{I}{\frac{1}{2}d},$$

S being the *coefficient of strength* to be determined by experiment. If d_1 is the depth of the web, or part between the top and bottom flanges, b the breadth of each flange, t the thickness of the web, we have from (**12**),

$$I = \tfrac{1}{12}(bd^3 - (b - t)\, d_1^3).$$

When the beam of length l is loaded in the middle with a weight W, and supported at the ends, we have by (**8**), the moment of the strain equal to $\frac{1}{4}W \,.\, l$. Equating this with the above value of M, we get

$$W = \tfrac{2}{3} S \frac{bd^3 - (b - t)\, d_1^3}{d \,.\, l}.$$

To determine the value of S, we take an example tested by Barlow,* in which $d = 5$ in., $d_1 = 2{\cdot}5$, $l = 54$, $b = 2{\cdot}125$, $t = {\cdot}85$. This beam bore $8\frac{1}{2}$ tons without the elasticity being injured, so that we may take 4 tons as the *safe permanent load.* Substituting these values in the formula, we get,

$$S = \tfrac{3}{2} \frac{W.\ d.\ l}{bd^3 - (b - t)\, d_1^3} = \tfrac{3}{2} \frac{8960 \times 5 \times 54}{265{\cdot}6 - 20} = 14769.$$

Therefore the *safe permanent load* (W) of a rolled joist of I section may be found from the formula,

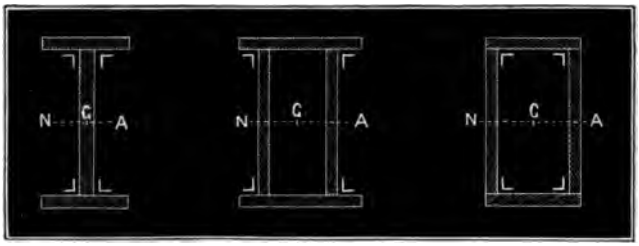
$$W = 9846 \frac{b \,.\, d^3 - (b - t) d_1^3}{d \,.\, l}.$$

* Barlow, *On Strength of Materials.* (Lockwood and Co. 1869.)

In the foregoing formula all the dimensions are expressed in inches, and the weight in pounds.

Large beams are made by riveting rolled plates together by means of angle-iron, either in the I form of

Fig. 38. Fig. 39. Fig. 40.



section (fig. 38), or in the box form (figs. 39, 40). The box-girder is found by Fairbairn to be stronger than that having the I form and of the same weight, in the proportion of 100 to 93. If we put b as the breadth of the top and bottom plate, d the total depth of the beam in the middle, d_1 the depth between the top and bottom plates, and t the total thickness of the plates forming the web or vertical part; l being the span; (all the dimensions in inches); then the formula for the breaking-weight in the middle is obtained in a similar manner to that for rolled joists;

$$W = 12 \frac{b\,d^3 - (b - t)\,d_1^3}{d\,.\,l}, \text{ in tons.}$$

The multiplier 12 is derived from an average of the results of Hodgkinson's experiments, as given in the 'Report of the Commissioners on the Application of Iron to Railway Purposes.' The strength of an I-girder is rather less for the same weight of metal than that of the box-girder, and may be found by multiplying the value of W obtained above by ·93.

Some authorities recommend that the top plate should be somewhat thicker than the bottom, as the resistance of wrought-iron to extension is half as much again as its resistance to compression. But if we compare the results of Hodgkinson's experiments, we find that no appreciable advantage is obtained in a beam whose top is thicker than its bottom flange, over another beam having equal flanges, where the weights of the two beams are the same.

Let us apply the formula to a box-girder having $b = 24$, $d = 36$, $l = 540$, $t = 2 \times \cdot 214 = \cdot 428$, $b - t = 23 \cdot 572$, thickness of top plate $= \cdot 5625$, thickness of bottom plate $= \cdot 397$, $d_1 = 35 \cdot 0405$; then we have the breaking-weight,

$$W = 12 \frac{24 \times 36^3 - 23 \cdot 572 (35 \cdot 0405)^3}{36 \times 540} = 63 \cdot 94 \text{ tons.}$$

The *permanent safe load* should in no case exceed one-third the breaking-weight.

The line N A is the *neutral-axis* passing through the centre of gravity G of the sections, and about which line the moment of inertia is taken.

If the load is uniformly distributed, the beam will bear twice as much as when the weight is concentrated at the centre, as previously shown (**35**). Also when a beam is fixed at one end and loaded at the other, the breaking-weight is one-fourth of that obtained by the formula just given for a beam supported at each end.

It will be seen from the formula that if all the dimensions of a beam are doubled, the value of W is increased four times; if they are trebled, the value of W is in-

creased nine times; and so on. Hence it appears that if the proportions of a beam remain the same, and the actual dimensions are increased, the strength is increased as the second power, or *square*, of the lineal dimensions. This is very nearly borne out by experiments; the average of which gives 1·9 rather than 2 as the power according to which the strength increases.

In wrought-iron girders the flanges or '*booms*,' as they are termed in large beams, are the only parts that have to resist flexure; whilst the web has to resist the *shearing* force (**9**). The resistance to shearing may be considered as equivalent to the resistance to tension. The top flange will be subjected to a compressive force, and the bottom flange to an extending force; now since the resistance to compression is less in wrought-iron than the resistance to extension, it would appear that the area of the upper flange should be greater than that of the lower one in like proportion, or as 3 to 2.

48. For wrought-iron beams of very large size, such as are required for bridges, the 'lattice' principle is generally used. The beams so called are made of section shown in figs. 38, 39, 40, but with the vertical plates replaced by cross-bars of angle and tee-iron riveted to bars of flat iron at their intersections, and also to narrow vertical plates which are themselves riveted to the top and bottom flange, forming the *booms*. Consequently almost the whole of the forces of compression and extension are confined to the booms, as the lattice bars only imperfectly represent the web of solid plates used in the box-girder. Fairbairn considers the strength of this beam to be to that of

the box-girder in the proportion of 84 to 100, the weights being equal. The foregoing formula for box-girders may be applied to find the strength of a lattice-girder, by first ascertaining the thickness of vertical plate which would have the same weight as the lattice bars, and calculating the strength of such a box-beam; then the strength of the lattice-beam is found by multiplying the result by ·84. The lattice-girder has an advantage in exposing a smaller surface to the wind than a solid box-beam, and is therefore preferable for railway bridges. A very full investigation into the strains in lattice-girders will be found in Stoney's 'Theory of Strains;' Unwin's 'Lectures on Roofs and Bridges;' and in Humber's 'Handybook of Strains.'

The method of calculating with greater accuracy the strength of large tubular-girders is given in the Report of the Commissioners on the use of Iron for Railway Purposes; also in Tait's 'Treatise on the Strength of Materials.'

In order that a wrought-iron girder, whose breadth is the same throughout, may have a uniform strength in every part, when the load is equally distributed, the depth must diminish from the centre towards the two ends in the ratio of the ordinates of an ellipse (fig. 37).*

49. ELASTICITY.—When wrought-iron in the form of bars is subjected to a longitudinal stretching-force, it will sustain a weight of 25 tons for every square inch of section before being torn asunder. This amount may therefore be taken as the breaking-weight of wrought-iron bars which are subjected to no other

* Page 87.

strain but that of extension in the direction of their length. The extent to which a vertical rod of iron will be stretched by a given weight W (expressed in pounds), suspended from one end is,

$$l = \frac{W \times L}{E \times A},$$

where E is the *modulus of elasticity* (**11**), which, according to Rankine,* is 29,000,000; L being the original length of the bar; and A the area of section.

From this formula it appears that the elongation is directly proportional to the stretching-force; which is, however, only true within certain limits, and will not be true if W exceeds the *limit of elasticity*, or is more than the bar will bear without its elasticity being injured. The elongation is also *directly* proportional to the original length of the bar, and is *inversely* proportional to its area of section. As an example, to find how much an iron rod, 1 inch square and 36 inches long, will be stretched by a weight of 10 tons suspended from one end; in this case we have,

$$l = \frac{10 \times 2240 \times 36}{29{,}000{,}000 \times 1} = \cdot 0278 \text{ inch.}$$

The experiments made by Kirkaldy give 25 tons per square inch for the tensile strength of wrought iron in *bars*, and 22 tons for wrought-iron plates.

50. DEFLEXION.—When a wrought-iron beam supported at each end is loaded in the middle, the deflexion produced will be proportional to the amount

* *Applied Mechanics.*

of the load, so long as it does not exceed one-half the breaking-weight of the beam; but beyond that limit the deflexion increases more rapidly as the load approaches the breaking-weight, in consequence of the elasticity being impaired. It is shown by writers on the strength of materials, that where the beam has equal top and bottom flanges, the deflexion is expressed by the formula,

$$D = \frac{W}{48E} \times \frac{l^3}{I} = \frac{W}{4E} \times \frac{l^3}{bd^3 - (b - t)\,a_1^3},$$

in which D is the deflexion, l the span, W the load, I the moment of inertia of the section about the neutral axis NA (figs. 38, 39, 40).* To obtain the value of E we take a specimen of a rolled iron joist experimented upon by Barlow, the dimensions of which are given in (**47**). It was found to deflect ·016 in. for every ton of load, so that we can find E in this case from the equation,

$$E = \frac{W \times l^3}{48D \times I} = \frac{W \,.\, l^3}{4D\,(bd^3 - (b - t)\,d_1^3)} = 10{,}030,$$

all the dimensions being in inches, and W in tons. Let us apply this formula to find the deflexion of the box-girder whose breaking-weight we found above (**47**); and let the load in the centre be 33 tons; then,

$$D = \frac{33 \times (540)^3}{40120 \times 105627} = 1{\cdot}23 \text{ inch.}$$

With half this load, or $16\frac{1}{2}$ tons, the deflexion in the

* Page 94.

middle will be ·615 inch, which amounts to no more than the $\frac{1}{878}$th part of the span; a deflexion which would be quite invisible to the eye; so that we may consider that a permanent load of at least 16 tons may be safely laid on the centre of this beam; and this is about one-fourth of its breaking-weight.

The value of the *modulus* E varies according to the *quality* of the iron used, and can readily be found by experiment.

When the load is uniformly distributed over the entire length of the beam, the deflexion is five-eighths of that produced by the same load placed at the middle. So that the deflexion due to the weight of the beam itself is five-eighths of that which would be produced if its whole weight were concentrated at the middle and the beam itself supposed without weight. Also, in calculating the deflexion of a beam by a given load, we must add five-eighths of the beam's own weight to the load laid on the middle, to get the true strain. In the last example, the weight of the beam is not considered; but as this amounts to 3 tons, the true deflexion will be that due to 33 + $\frac{5}{8}$ 3, or nearly 35 tons. The true value of D is therefore 1·3 inch.

51. When a mass of iron is exposed to alterations of temperature, it continually changes its dimensions, being larger at a high temperature than at a low one; that is to say, it expands in dimension as the temperature increases. When the temperature rises from 32° Fahrenheit to 212°, iron expands the 900th part of each dimension, its relative proportions remaining the same. Thus a bar of iron 75 feet long will expand

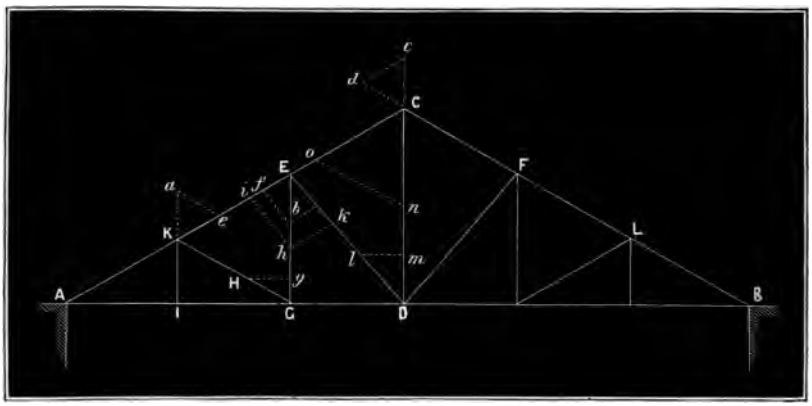
1 inch in length while passing from 32° to 212°, or through 180° of temperature. When iron is used in construction it is exposed in this country to a variation of about 90° during the year, so that a beam 75 feet long will alter half an inch in length between summer and winter. In cases where it is exposed to the full force of the sun in summer, and the greatest degree of cold in winter, the variation will be considerably more. It therefore is absolutely necessary that all large masses of iron should have a certain amount of *play* allowed them, as the expansion and contraction are irresistible forces, and will tear asunder or thrust over any structure that may oppose.

This property of expansion and contraction has been employed for the purpose of drawing together walls which have been forced out of their perpendicular in opposite directions. Iron bars with nuts and screws being placed tightly across from wall to wall, are heated in the middle, when they expand and loosen the screws which are then tightened up; and as they cool, the contracting force of the bars gradually pulls the walls towards each other. This process being repeated carefully several times the walls may be brought to their original state of uprightness.

52. Roofs.—Wrought-iron is much used in the framework of roofs of large span. Fig. 41 represents a common form of iron roof. The tie-rod AB being subjected to a stretching force in the direction of its length, and a very slight amount of transverse strain between the several points of support from its own weight, is made of round or flat bar-iron. The rafters

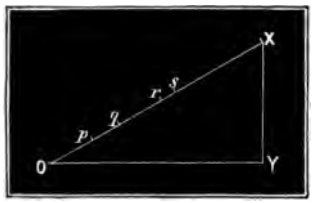
AC, BC having to sustain both a longitudinal and transverse strain are made of tee-iron. The struts ED, KG having to sustain a compressing and transverse strain are made either of angle or tee-iron; and the vertical rods CD, EG, KI, having only to sustain a stretching

Fig. 41.



force in the direction of their length, are of round iron. Let W be the entire weight which this truss has to sustain; then $\frac{1}{6}$ W is supported *directly* at each of the points K, E, C, F and L; $\frac{1}{12}$ W *directly* at A and B. Let the lines C*c*, E*b*, K*a*, be equal, and each represent on a scale $\frac{1}{6}$ W. Draw the parallelogram C*c*, making C*d* parallel to BC, and *cd* to AC; then *dc* represents the resolved part of $\frac{1}{6}$ W acting down the rafter AC. Draw OX (fig. 42) parallel to AC, and OY parallel to AB; and take O*p* equal to *cd*. At E (fig. 41) draw the parallelogram E*b*, then E*f* is the resolved part of $\frac{1}{6}$ W acting at E,

Fig. 42.



down the rafter AC; *fb* the resolved part down the strut ED. Take *pq* (fig. 42) equal to E*f*.

At K (fig. 41) draw *ae* parallel to KG, then K*e* is the resolved part of $\frac{1}{6}$ W at K down AC, and *ae* is the resolved part down the strut KG. Make *qr* (fig. 42) equal to K*e*. Take GH (fig. 41) equal to *ae*, draw the horizontal H*g*, then G*g* (= $\frac{1}{2}$ K*a*) is the vertical strain on EG from the strut KG; take *bh* = G*g*, and draw *hi* parallel to ED; then *if* is the resolved part in the direction of AC; take *rs* (fig. 42) equal to *if*. E*k* (fig. 41) represents the compression on the strut ED, which is conveyed to D; take D*l* = E*k*, and draw *lm* horizontal; then twice D*m* represents the vertical strain on CD caused by the two struts ED, FD. Take C*n* = 2 D*m*, draw *on* parallel to CB; then C*o* is the compression down AC produced by the rod CD. Take *s*X (fig. 42) equal to C*o*; then the line OX represents the total compression down AC on the same scale that C*c* represents $\frac{1}{6}$ W. Draw the perpendicular YX (fig. 42), then OY represents the horizontal strain on the tie-rod.

By this means the strains on the several pieces of the framework can be readily found by measuring with a scale.

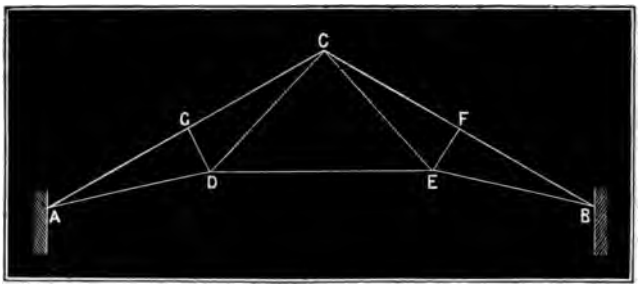
One half the weight of the tie-rod is sustained by the five vertical rods, so that each has one-tenth of the weight of the tie-rod added to the other strains. This is, however, generally of but small amount.

The analytical methods of finding the strains on the several parts of a roof, will be found in Fenwick's 'Mechanics of Construction,' Rankine's 'Ap-

plied Mechanics,' or Unwin's 'Lectures on Roofs and Bridges.'

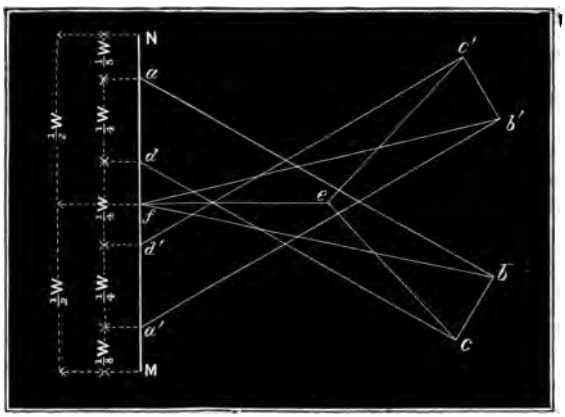
53. Professor Maxwell's method of diagrams, which has been previously described (**3**), enables us readily to find the relative strains on the different parts of an iron roof. The following is an example of its application to a common form of roof (fig. 43). Let W

Fig. 43.



represent the total vertical weight which the truss has to bear; then $\frac{1}{8}$ W is *directly* supported at A and B;

Fig. 44



$\frac{1}{4}$ W at G, C and F. The vertical reaction at A and B is $\frac{1}{2}$ W

Now draw a vertical line M N (fig. 44) whose length represents the weight W on any convenient scale; bisect M N in *f*. Take N*a*, M*a'*, *fd*, *fd'*, each equal (on the above scale) to $\frac{1}{8}$ W.

Draw *ab* and *dc* parallel to B C (fig. 43); *fb* parallel to B E; *bc* parallel to E F; *ce* parallel to E C; *fe* parallel to D E; and so also for the opposite side. Then, if we measure the lengths of the several lines thus drawn on the above scale, we obtain the strains in the several parts of the roof to which they are respectively parallel.

Thus, *f*N represents the reaction at A or B, and equals $\frac{1}{2}$ W; N*a* the load supported at the joints A or B, and equals $\frac{1}{8}$ W; *ad* the vertical pressure at G or F, and equals $\frac{1}{4}$ W; *dd'* the vertical pressure at C, and equals $\frac{1}{4}$ W; *ab* the strain down A G or B F; *dc* the strain down C G or C F; *bc* the strain along E F or G D; *bf* the strain along B E or A D; *ec* the strain along E C or D C; *fe* the strain along D E. Several examples of the application of this method will be found in Unwin's 'Lectures on Iron Roofs and Bridges.'

54. STEEL.—Where great strength combined with lightness is required, steel is the material which is most useful. The strength of steel varies according to the proportion of pure carbon which it contains, varying in different qualities from three-eighths to two per cent. In wrought-iron the quantity of carbon is from one-eighth to one-half per cent; and in cast-iron from two-and-a-half to five per cent.

From experiments made by Mr. Vickers of Sheffield,*

* Paper read at Institution of Mechanical Engineers, 1861.

it appears that the *tensile* strength of steel is increased by the addition of carbon until the proportion reaches 1¼ per cent., the breaking strain being then as high as 69 tons per square inch. Beyond this degree of carbonisation, the steel becomes gradually weaker until it reaches the form of cast-iron, and will sustain a tensile strain of only 6 or 6½ tons per square inch.

For sustaining blows, however, it is found that the steel cannot contain too little carbon; any increase in the quantity of carbon being accompanied by an increase of brittleness. It is therefore necessary in practice to obtain a material which shall combine the power of resisting a tolerably high tensile as well as transverse strain; and these qualities are found in steel that contains five-eighths to three-fourths per cent. of carbon, and in which the tensile strength is from 45 to 50 tons per square inch of section; the specific gravity being 7·85.

Experiments by Major Wade (U.S. Army) on small cast-steel cylinders, whose length was about 2½ diameters, gave the crushing strength of steel, not hardened, at 89 tons per square inch of section; and for hardened steel of 'mean temper,' 175 tons per inch. The crushing strength of steel of 'high' or of 'low' temper was rather less than that of the 'mean.'

A large number of experiments were made by Fairbairn on steel of various qualities and from several different manufacturers.* The *modulus of elasticity* from thirty of the best specimens averaged 31,000,000; whilst in some of the inferior qualities it was only two-

* *Report of British Association*, 1867.

thirds of that value. The average tensile strength of thirty of the best specimens was found to be 47·7 tons per square inch, or about double that of hammered iron. The resistance to compression was about double the resistance to extension. Hence it follows that a horizontal steel beam having a top and bottom flange, and being strained transversely, should have the area of section of the bottom flange made double that of the top flange.

It is found that when a steel beam is subjected to a transverse strain, the strain corresponding to the *elastic limit* approaches more nearly the breaking weight than it does in iron; and consequently that a steel beam may be over-loaded with greater safety than an iron one.

CHAPTER VII.

WATER CONTAINED IN VESSELS AND PIPES.

55. WHEN a body having a level surface is immersed in water, it is pressed upon by a weight which is equal to that of a column of water, whose base is the area of the surface immersed, and whose height is its depth below the top of the water. If the surface of the body immersed is not parallel to that of the water, the pressure upon it is that of a column of water whose base is the area of the immersed surface, and whose height is the depth of its centre of gravity below the surface of the water.

For example, the pressure on the bottom (supposed to be level) of a tank full of water is the weight of a column of water whose base is the area of the bottom, and height the depth of the tank; and it is independent of the form of the tank, being the same whether the sides are sloping or vertical. Thus, in the three tanks (fig. 45) A, B, and C, having equal bases and the

Fig. 45.

same depth, the pressure on the bottom will be the

same in all when filled with water. The pressure of the water on the *side* of a full tank, whether vertical or inclined, is found by multiplying the area of its surface by the depth of its centre of gravity below the top of the tank, and the result by the weight of a cubic foot of water. If the side is rectangular, the centre of gravity is at a depth equal to half that of the tank; so that the pressure on each side of a cubical vessel is half that on its bottom.

The pressure on the side of a tank is also quite independent of the area of surface which the bottom of the tank covers, being the same for a narrow vessel as for one of unlimited extent; provided only that the area of the side itself and the *depth* of the water remain unaltered.

When a tank has sloping sides, which are wider at the top than at the bottom, the position of the centre of gravity of any side must be determined as in (**5**). Let d be the vertical depth of the tank, h the height of a side measured on the slope, a the breadth at top, b the breadth at bottom; then the pressure on the side, when the tank is full, is that of a column of water whose base is $\frac{1}{2}(a + b)h$, and whose height is $\frac{d}{3} \times \frac{a + 2b}{a + b}$.

56. CENTRE OF PRESSURE.—When a rigid plane is pressed upon by water in which it is immersed, there is one point in that plane at which the resultant of all the pressures acts; and this point is called the 'centre of pressure.' If, therefore, a force equal to the resultant is applied at the *centre of pressure*, all the

pressures will be counterbalanced, and the plane will be in equilibrium.

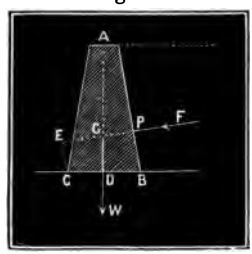
The position of the centre of pressure can only be obtained by help of the higher mathematics, the methods of which will be found in any analytical treatise on hydostatics. The position of the *centre of pressure* in a rectangular plane immersed in water is shown to be at one-third of its height from the base, measured up the centre-line. Hence it follows that when a tie-rod is placed across from side to side of a tank having vertical sides, its position must be in the middle of the side at one-third of its depth from the bottom.

In a plane of which the top and bottom are parallel, but of different widths, where a is the width at top, b that at bottom, and h the height or distance between the top and bottom; the distance of the *centre of pressure* from the top is

$$\frac{h}{2} \times \frac{a + 3b}{a + 2b};$$

and if $a = 2b$, the distance of the centre of pressure from the top is $\frac{5}{8}h$; the distance being in all cases measured on the centre line at right angles to the base.

Fig. 46.

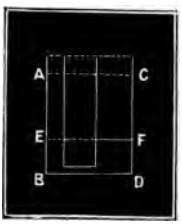


Let ABC (fig. 46) be the section of the wall of a reservoir full of water; F the pressure of the water acting perpendicularly to AB at P, the *centre of pressure.* Let W be the weight of the wall acting vertically at G, its centre of gravity. Draw EC perpendicular to the direction of the force F.

Then, in order that the wall may not be overthrown, we must have F × EC less than W × DC.

57. When vessels of different sizes are placed on the same level, and made to communicate by a pipe at the bottom, water poured into one vessel will rise to the same level in all. Thus, let the small vessel (fig. 47) AB be filled up to A, the water will rise in the larger one CD to C, and the line AC will be horizontal; so that the weight of the small quantity of water in AB balances that of the larger quantity in CD. Suppose the vessel CD be closed tightly by a plug at any point F, and let AB be filled up to A with water. Draw the horizontal line EF; then the column of water AE exerts a pressure upwards on the underside of the plug at F. If A is the area of section in square inches of the larger vessel, a that of the smaller, p the pressure per square inch of the column AE; then $p \times a$ is the pressure at E of the column AE, and $p \times A$ the pressure upwards on the plug at F; or the pressure at F is to that at E as $p \,.\, A$ to $p \,.\, a$, or as A to a. Therefore, pressure on the underside of the plug at $F = \frac{A}{a} \times$ weight of column AE.

Fig. 47.



Hence we see that the pressure upwards on the plug is increased by diminishing a, the area of the smaller vessel, or by increasing the area A of the larger one, as well as by increasing the height of the column AE; so that a very small quantity of water may produce a very great pressure on a large surface. This principle is applied to the construction of hydraulic lifts; a

piston being substituted for the plug in the larger vessel, which is raised by the pressure of water from a small tube carried up to a tank in the highest part of the building. If the area of the piston is 50 times that of the section of the tube, the pressure upwards upon it will equal 50 times the weight of the column AE; so that it will not only be made to ascend, but will also be capable of raising a heavy weight with it, until equilibrium is established by the gradual decrease of the head of water, or of the height AE.

58. SPECIFIC GRAVITY.—When a heavy substance is placed in one scale of a pair of balances, it is said to have the same weight as another heavy body placed in the opposite scale, when they exactly balance. If the heavy substance instead of being placed in the scale is suspended from the bottom of it in a vessel of water, it is now found that the weight in the opposite scale more than balances it, and that it has lost a certain amount of weight. This loss of weight is due to the upward pressure of the water upon the body, and which is equal to the weight of water which it displaces, or to a quantity of water equal in bulk to that of the heavy body. Let w be the weight of the body in air, w' its weight in water; then $w - w'$ is the weight of an equal bulk of water. The proportion which the weight of any body bears to the weight of an equal bulk of water is called its 'specific gravity.' The *specific gravity* therefore of a body is,

$$\frac{w}{w - w'}.$$

Tables have been formed of the *specific gravity* of

almost all known substances,* and, having ascertained the specific-gravity of a body, we are at once made acquainted with many of its properties—as its hardness, density, weight, &c. If we take the weight of a cubic foot of water as 1,000 oz. or 62½ lbs., we have only to multiply the specific-gravity of a body by 62½ lbs. and we find the weight per cubic foot of that substance. We are also enabled to detect any unsoundness in a mass of cast metal which may appear externally to be perfect, but, from cooling too rapidly, has become honey-combed in the interior, as its specific-gravity will in that case be less than for a solid mass of the same metal. The impurities of metals can also be detected by finding their specific-gravity; and also the proportion in which the two metals in any alloy are mixed can be determined. Brass, being a mixture of copper and tin, has a specific-gravity between those of these two metals; the specific-gravity of copper is 8·9, and of tin, 7·29; that of brass varies from 7·8 to 8·4, according to the proportions in which these metals are mixed.

To find the specific gravity of wood, or of any substance lighter than water, let it be made to sink by attaching a heavy body whose weight in water is w_1; and let w' be the weight of the two bodies in water, then the specific-gravity required in

$$\frac{w}{w + w_1 - w'}.$$

It often happens that a baulk of timber is rotten in

* See page 117.

the middle, from the pith having decayed, (**33**) by which its value when cut up is much diminished; this can be at once detected by finding the specific gravity of the baulk and comparing it with that of a piece of the solid wood.

59. WATER IN PIPES.—When water is conveyed from one reservoir to another by means of a long pipe descending from the first and passing under ground to the second, it ought according to the theory of hydrostatics (**57**) to rise to the same height in the second as in the first reservoir. But this is found in practice to be far from the case when the pipe is long, as its surface offers a certain resistance to the passage of the water, thereby retarding its velocity; so that the effect of the *head* of water is diminished. It is found that this resistance is independent of the height of the *head*, but is nearly as the square of the velocity at which the water is passing along the pipe; and is also proportional to the surface of the pipe itself which is exposed to the action of the water; so that as the surface of a circular cylinder is the smallest for a given area of section, it is advisable to make pipes and channels for conveying water as nearly circular as possible, in order to reduce their resistance to a minimum.

If we call f the co-efficient of friction which is determined by experiment, l the length and d the diameter of the pipe, in feet; v the velocity in feet per second; g the force of gravity, or 32·2 in this latitude; then δ, the *loss of head*, is found to be nearly,

$$\delta = f \frac{l}{d} \cdot \frac{v^2}{2g}, \text{ in feet.}$$

The value of f is not, however, quite constant, being greater for low than for high velocities; its value is given in Weisbach's 'Principles of Mechanics' as

$$f = \cdot 01482 + \frac{\cdot 017963}{\sqrt{v}}.$$

From this we find that when

$v =$ 1 foot per sec., $f = \cdot 0317$,
$v =$ 2 „ $f = \cdot 0266$,
$v =$ 3 „ $f = \cdot 0244$,
$v =$ 5 „ $f = \cdot 0221$,
$v =$ 10 „ $f = \cdot 0199$.

For example, suppose a pipe, 8 in. diameter and 2,000 ft. long, conveys water at a velocity of 3 ft. per second; the *loss of head* will be,

$$\delta = \cdot 0244 \frac{2000}{\frac{2}{3}} \cdot \frac{9}{64 \cdot 4} = 10 \cdot 23 \text{ feet.}$$

It appears from the formula that in order to obtain the least possible *loss of head* in leading a quantity of water, the pipe must be made as wide as possible and not unnecessarily long.

If Q is the discharge, F the transverse section of the pipe $= \pi \frac{d^2}{4}$, $(\pi = 3 \cdot 1416)$;

$$\text{then, } v = \frac{Q}{F} = \frac{4Q}{\pi d^2}.$$

Substitute this value for v in the formula for *loss of head*, and we have,

$$\delta = \frac{f}{2g} \left(\frac{4}{\pi}\right)^2 \frac{l \cdot Q^2}{d^5};$$

from which it is seen that if all the other qualities remain unaltered, and $2d$ is put for d; then the value of δ must be divided by 2^5 or 32.

This last formula tells us how much *fall* we must give to a pipe, in order that it may convey a given quantity Q from one place to another. In the previous example, if a *fall* of 10·23 feet is required to convey a given quantity in a pipe of 8 inches diameter, then a *fall* of only $\frac{10{\cdot}23}{32}$, or ·32 feet, is required to produce the same discharge from a tube 16 inches diameter.

To find the velocity v, in feet per second, of the discharge of water from long tubes, where h is the *head* in feet, we have

$$v = \sqrt{\frac{2\,g.h.d}{f.l}},$$

$$\text{and, } Q = F\,.\,v = \frac{\pi d^2}{4}\,v.$$

In all cases the pipes are supposed to be running full.

Much information on the subject of the flow of water in pipes and channels will be found in Downing's 'Practical Hydraulics,' in Neville's 'Hydraulic Tables, Co-efficients, and Formulæ,' and in Gregory's 'Mathematics for Practical Men,' (4th Edit. 1862.)

APPENDIX.

Weight of Building Materials.

THE following is a Table of the specific-gravity and weight per cubic foot of some of the principal materials used for building purposes :—

Materials	Spec. grav.	Weight of 1 cub. ft. in lbs. av.
Water	1000	62·50
Beech, dry	690	43·12
Elm, seasoned	553	34·56
Fir (Norway spruce)	512	32·00
„ (white American spruce)	465	29·06
„ (Memel), dry	544	34·00
„ (Riga), dry	466	29·12
Pine (American), dry	368	23·00
„ (American pitch), dry	936	58·50
„ („), seasoned	741	46·31
Mahogany (Spanish), dry	852	53·30
„ (Honduras), dry	560	35·00
Oak (Old English), dry	625	39·06
„ (English) seasoned	777	48·56
„ (Riga), dry	688	43·00
„ (Dantzic) seasoned	755	47·24
„ (American), red	752	47·00
„ („), white	840	52·50
Teak, dry	745	46·56
„ seasoned	657	41·06
Granite (Guernsey)	2999	187·47
„ (Aberdeen)	2664	166·50
„ (Cornish)	2624	164·00
„ (Dublin)	2713	169·57
Slate (Welsh)	2888	180·50
„ (Westmoreland)	2768	173·00
„ (Cornwall)	2512	157·00
SANDSTONES :—		
Abercarne (Monmouth)	2688	167·93
Pyotdykes (Dundee)	2601	162·57
Glammis (Forfar)	2578	161·20

Materials	Spec. grav.	Weight of 1 cub. ft. in lbs. av.
SANDSTONES (*continued*) :—		
Munlochy (Ross)	2569	160·60
Mylnefield (Dundee)	2561	160·07
Auchray (ditto)	2542	158·90
Lochee (ditto)	2538	158·70
Scotgate-head (Huddersfield)	2528	158·00
Colford (Gloster)	2491	155·72
Longwood (Huddersfield)	2455	153·44
Elland (Halifax)	2452	153·28
Park-spring (Leeds)	2418	151·11
Talacre (Flint)	2403	150·27
Mansfield, red	2378	148·66
„ white	2344	146·51
Darley-dale, Derby	2372	148·25
New Leeds (Yorkshire)	2360	147·50
Chepstow (Monmouth)	2348	146·78
Bewdley (Salop)	2336	146·00
Kenton (Northumberland)	2320	145·00
Giffneuk (Glasgow)	2303	143·90
Hookstone (Harrogate, Yorkshire)	2282	142·62
Stainton (Durham)	2280	142·53
Bramley-fall (Leeds)	2276	142·23
Catcraig (Linlithgow)	2267	141·70
Cragleith (Edinboro')	2266	141·63
Humbie („)	2244	140·23
Meanwood (Leeds)	2238	139·88
Redgate (Durham)	2234	139·62
Hunger-hill (Belper)	2175	135·95
Gatherley (Yorkshire)	2173	135·82
Pensher (Durham)	2148	134·35
Hollington (Stafford)	2129	133·10
Duffield (Derby)	2127	132·90
Longannet (Perth)	2108	131·73
Heddon (Northumberland)	2092	130·73
Morley-moor (Derby)	2089	130·54
Whitby (Yorkshire)	2027	126·70
Tixall (Stafford)	1993	124·56
Calverley (Kent)	1889	118·06
Tisbury (Wilts)	1778	111·13
Gatton (Reigate)	1650	103·10
MAGNESIAN LIMESTONES :—		
Bolsover (Derby)	2427	151·69
Anston (Yorkshire)	2304	144·00
Roche-abbey (Bawtry, Yorkshire)	2228	139·20
Huddlestone (Sherburne „)	2205	137·83
Park-nook (Doncaster „)	2198	137·20
Brodsworth („ „)	2138	133·66
Cadeby („ „)	2026	126·60

Materials	Spec. grav.	Weight of 1 cub. ft. in lbs. av.
OOLITES :—		
Wass (Thirsk, Yorkshire), hard	2600	162·50
„ („ „), soft	2267	141·68
Aubigny (France)	2400	150·00
Ancaster (Lincoln)	2229	139·30
Barnack (Stamford, Lincoln)	2188	136·78
Taynton (Oxon)	2175	135·93
Windrush (Gloster), hard	2175	135·93
„ („), soft	1891	118·18
Portland (Waycroft)	2169	135·56
„ (Roach)	2028	126·80
Doulting (Wilts)	2147	134·25
Haydor (Lincoln)	2135	133·48
Ketton (Rutland)	2045	127·81
Caen (France), average	2000	125·00
Box (Bath)	1968	123·00
Coombe-down (Bath)	1856	116·00
LIMESTONES :—		
Kentish-rag (Maidstone)	2666	166·60
Hopton-wood (Derby)	2535	158·45
Chilmark (Wilts), hard	2518	157·38
„ („), soft	2426	151·60
Blue-lias	2467	154·18
Seacombe (Purbeck)	2416	151·03
Chalk	2315	144·68
Hamhill (Somerset)	2268	141·75
Hildenley (Malton, Yorkshire)	2202	137·65
Barnack (Lincoln)	2188	136·76
Sutton (Glamorgan)	2176	136·00
Beer (Devon)	2108	131·75
Totternhoe (Beds)	1864	116 50
Earth, loamy	2016	126·00
„ common	1984	124·00
„ clay	1919	119·93
„ gravel	1749	109·32
„ loose	1520	95·00
Concrete	2240	140·00
Brickwork	1792	112·00
Mortar	1744	109·00
Iron, wrought	7680	480·00
„ cast	7120	444·00
Steel	7840	490·00
Lead, milled	11,407	712·93
Copper, sheet	8785	549·06
Brass, cast	8100	506·25
Bell-metal	8760	547·50
Zinc	7028	439·25

Materials	Spec. grav.	Weight of 1 cub. ft. in lbs. av.
Glass, plate	2760	172·50
„ crown	2520	157·50
Brick, stock	1841	115·06
„ red	2168	135·50
Tile, plain	1815	113·43

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

LONDON, *June*, 1870.

A Catalogue

OF

NEW & STANDARD WORKS

IN

ENGINEERING, ARCHITECTURE, AGRICULTURE, MATHEMATICS, MECHANICS, SCIENCE, &c. &c.

PUBLISHED BY

LOCKWOOD & CO.,

7, STATIONERS'-HALL COURT, LUDGATE HILL, E.C.

ENGINEERING, SURVEYING, &c.

Humber's New Work on Water-Supply.

A COMPREHENSIVE TREATISE on the WATER-SUPPLY of CITIES and TOWNS. By WILLIAM HUMBER, Assoc. Inst. C.E., and M. Inst. M.E. Author of "Cast and Wrought Iron Bridge Construction," &c. &c. This work, it is expected, will contain about 50 Double Plates, and upwards of 250 pages of Text. Imp. 4to, half bound in morocco. [*In preparation.*

*** *In accumulating information for this volume, the Author has been very liberally assisted by several professional friends, who have made this department of engineering their special study. He has thus been in a position to prepare a work which, within the limits of a single volume, will supply the reader with the most complete and reliable information upon all subjects, theoretical and practical, connected with water supply. Through the kindness of Messrs. Anderson, Bateman, Hawksley, Homersham, Baldwin Latham, Lawson, Milne, Quick, Rawlinson, Simpson, and others, several works, constructed and in course of construction, from the designs of these gentlemen, will be fully illustrated and described.*

AMONGST OTHER IMPORTANT SUBJECTS THE FOLLOWING WILL BE TREATED IN THE TEXT:—

Historical Sketch of the means that have been proposed and adopted for the Supply of Water.—Water and the Foreign Matter usually associated with it.—Rainfall and Evaporation.—Springs and Subterranean Lakes.—Hydraulics.—The Selection of Sites for Water Works.—Wells.—Reservoirs.—Filtration and Filter Beds.—Reservoir and Filter Bed Appendages.—Pumps and Appendages.—Pumping Machinery.—Culverts and Conduits, Aqueducts, Syphons, &c.—Distribution of Water.—Water Meters and general House Fittings.—Cost of Works for the Supply of Water.—Constant and Intermittent Supply.—Suggestions for preparing Plans, &c. &c., together with a Description of the numerous Works illustrated, viz:—Aberdeen, Bideford, Cockermouth, Dublin, Glasgow, Loch Katrine, Liverpool, Manchester, Rotherham, Sunderland, and several others; with copies of the Contract, Drawings, and Specification in each case.

Humber's Record of Modern Engineering, 1866.

A RECORD of the PROGRESS of MODERN ENGINEERING, 1866: Comprising Civil, Mechanical, Marine, Hydraulic, Railway, Bridge, and other Engineering Works, &c. By WILLIAM HUMBER, Assoc. Inst. C.E., and M. Inst. M.E., Author of "A Complete and Practical Treatise on Cast and Wrought-Iron Bridge Construction." Imp. 4to, with 36 Double Plates, drawn to a large scale, and Photographic Portrait of John Fowler, Esq., President of the Institution of Civil Engineers. Price 3*l.* 3*s.* half-morocco.

List of the Plates and Diagrams.

NAME AND DESCRIPTION.	PLATES.	NAME OF ENGINEER.
Abbey Mills Pumping Station, Main Drainage, Metropolis	1 to 4	Mr. Bazalgette, C.E.
Barrow Docks	5 to 9	Messrs. M'Clean & Stillman, [C.E.
Manquis Viaduct, Santiago and Valparaiso Railway	10, 11	Mr. W. Loyd, C.E.
Adams' Locomotive, St. Helen's Canal Railw.	12, 13	Mr. H. Cross, C.E.
Cannon Street Station Roof, Charing Cross Railway	14 to 16	Mr. J. Hawkshaw, C.E.
Road Bridge over the River Moka	17, 18	Mr. H. Wakefield, C.E.
Telegraphic Apparatus for Mesopotamia	19	Mr. Siemens, C.E.
Viaduct over the River Wye, Midland Railw.	20 to 22	Mr. W. H. Barlow, C.E.
St. Germans Viaduct, Cornwall Railway	23, 24	Mr. Brunel, C.E.
Wrought-Iron Cylinder for Diving Bell	25	Mr. J. Coode, C.E.
Millwall Docks	26 to 31	Messrs. J. Fowler, C.E., and William Wilson, C.E.
Milroy's Patent Excavator	32	Mr. Milroy, C.E.
Metropolitan District Railway	33 to 38	Mr. J. Fowler, Engineer-in-Chief, and Mr. T. M. Johnson, C.E.
Harbours, Ports, and Breakwaters	A to C	

The Letterpress comprises—

A concluding article on Harbours, Ports, and Breakwaters, with Illustrations and detailed descriptions of the Breakwater at Cherbourg, and other important modern works; an article on the Telegraph Lines of Mesopotamia; a full description of the Wrought-iron Diving Cylinder for Ceylon, the circumstances under which it was used, and the means of working it; full description of the Millwall Docks; &c., &c., &c.

Opinions of the Press on the Volume for 1866.

"Mr. Humber's 'Record of Modern Engineering' is a work of peculiar value, as well to those who design as to those who study the art of engineering construction. It embodies a vast amount of practical information in the form of full descriptions and working drawings of all the most recent and noteworthy engineering works. The plates are excellently lithographed, and the present volume of the 'Record' is not a whit behind its predecessors."—*Mechanics' Magazine*, July 17, 1868.

"We gladly welcome another year's issue of this valuable publication from the able pen of Mr. Humber. The accuracy and general excellence of this work are well known, while its usefulness in giving the measurements and details of some of the latest examples of engineering, as carried out by the most eminent men in the profession, cannot be too highly prized."—*Artizan*, August 1, 1868.

"The volume forms a valuable companion to those which have preceded it, and cannot fail to prove a most important addition to every engineering library."—*Mining Journal*, July 11, 1868.

Humber's Record of Modern Engineering, 1865.

A RECORD of the PROGRESS of MODERN ENGINEERING, 1865, with Photographic Portrait of J. R. M'Clean, Esq., late President of the Institution of Civil Engineers. Half morocco, price 3*l.* 3*s.*

List of Plates and Diagrams.

MAIN DRAINAGE, METROPOLIS.

NORTH SIDE.

Map showing Interception of Sewers.
Middle Level Sewer. Sewer under Regent's Canal.
Middle Level Sewer. Junction with Fleet Ditch.
Outfall Sewer. Bridge over River Lea. Elevation.
Outfall Sewer. Bridge over River Lea. Details.
Outfall Sewer. Bridge over River Lea. Details.
Outfall Sewer. Bridges over Marsh Lane, North Woolwich Railway, and Bow and Barking Railway Junction.
Outfall Sewer. Bridge over Bow and Barking Railway. Elevation.
Outfall Sewer. Bridge over Bow and Barking Railway. Details.
Outfall Sewer. Bridge over Bow and Barking Railway. Details.
Outfall Sewer. Bridge over East London Waterworks' Feeder. Elevation.
Outfall Sewer. Bridge over East London Waterworks' Feeder. Details.
Outfall Sewer. Reservoir. Plan.
Outfall Sewer. Reservoir. Section.
Outfall Sewer. Tumbling Bay and Outlet.
Outfall Sewer. Penstocks.

SOUTH SIDE.

Outfall Sewer. Bermondsey Branch.
Outfall Sewer. Bermondsey Branch.
Outfall Sewer. Reservoir and Outlet. Plan.

MAIN DRAINAGE, METROPOLIS, *continued*—

Outfall Sewer. Reservoir and Outlet. Details.
Outfall Sewer. Reservoir and Outlet. Details.
Outfall Sewer. Reservoir and Outlet. Details.
Outfall Sewer. Filth Hoist.
Sections of Sewers (North and South Sides).

THAMES EMBANKMENT.

Section of River Wall.
Steam-boat Pier, Westminster. Elevation.
Steam-boat Pier, Westminster. Details.
Landing Stairs between Charing Cross and Waterloo Bridges.
York Gate. Front Elevation.
York Gate. Side Elevation and Details.
Overflow and Outlet at Savoy Street Sewer. Details.
Overflow and Outlet at Savoy Street Sewer. Penstock.
Overflow and Outlet at Savoy Street Sewer. Penstock.
Steam-boat Pier, Waterloo Bridge. Elevation.
Steam-boat Pier, Waterloo Bridge. Details.
Steam-boat Pier, Waterloo Bridge. Details.
Junction of Sewers. Plans and Sections.
Gullies. Plans and Sections.
Rolling Stock.
Granite and Iron Forts.

With copious Descriptive Letterpress, Specifications, &c.

Opinions of the Press on the Volume for 1865.

"Mr. Humber's works—especially his annual 'Record,' with which so many of our readers are now familiar—fill a void occupied by no other branch of literature. . . . . The drawings have a constantly increasing value, and whoever desires to possess clear representations of the two great works carried out by our Metropolitan Board will obtain Mr. Humber's last volume."—*Engineering.*

"No engineer, architect, or contractor should fail to preserve these records of works which, for magnitude, have not their parallel in the present day, no student in the profession but should carefully study the details of these great works, which he may be one day called upon to imitate."—*Mechanics' Magazine.*

"A work highly creditable to the industry of its author and to the skill and spirit of his publishers, and that will no doubt find eager readers in many a young engineer abroad or in the provinces, where good examples are rarer than with us 'Londoners.' . . . . The volume is quite an encyclopædia for the study of the student who desires to master the subject of municipal drainage on its scale of greatest development."—*Practical Mechanic's Journal.*

Humber's Record of Modern Engineering, 1864.

A RECORD of the PROGRESS of MODERN ENGINEERING, 1864; with Photographic Portrait of Robert Stephenson, C.E., M.P., F.R.S., &c. Half morocco, price 3*l.* 3*s.*

List of the Plates.

NAME AND DESCRIPTION.	PLATES.	NAME OF ENGINEER.
Birkenhead Docks, Low Water Basin	1 to 15	Mr. G. F. Lyster, C.E.
Charing Cross Station Roof—C. C. Railway.	16 to 18	Mr. Hawkshaw, C.E.
Digswell Viaduct—Great Northern Railway.	19	Mr. J. Cubitt, C.E.
Robbery Wood Viaduct—Great N. Railway.	20	Mr. J. Cubitt, C.E.
Iron Permanent Way.....	20*a*	
Clydach Viaduct—Merthyr, Tredegar, and Abergavenny Railway	21	Mr. Gardner, C.E.
Ebbw Viaduct ditto ditto ditto	22	Mr. Gardner, C.E.
College Wood Viaduct—Cornwall Railway ..	23	Mr. Brunel.
Dublin Winter Palace Roof.....	24 to 26	Messrs. Ordish & Le Feuvre.
Bridge over the Thames—L. C. & D. Railw.	27 to 32	Mr. J. Cubitt, C.E.
Albert Harbour, Greenock	33 to 36	Messrs. Bell & Miller.

With copious Descriptive Letterpress, Specifications, &c.

"The engineering annual before us fully maintains Mr. Humber's reputation as an author. It is, as it professes to be, a *resumé* of all the more interesting and important works lately completed in Great Britain; and containing, as it does, carefully executed drawings, with full working details, will be found a valuable accessory to the profession at large."—*Engineer.*

"Mr. Humber has done the profession good and true service, by the fine collection of examples he has here brought before the profession and the public."—*Practical Mechanic's Journal.*

Humber's Record of Modern Engineering, 1863.

A RECORD of the PROGRESS of MODERN ENGINEERING, 1863; with Photographic Portrait of John Hawkshaw, C.E., F.R.S., &c. Half morocco, price 3*l.* 3*s.*

List of the Plates.

NAME AND DESCRIPTION.	PLATES.	NAME OF ENGINEER.
Victoria Station and Roof—L. B. & S. C. Rail.	1 to 8	Mr. R. Jacomb Hood, C.E.
Southport Pier.....	9 and 10	Mr. James Brunlees, C.E.
Victoria Station and Roof—L. C. & D. & G. W. Railways	11 to 15A	Mr. John Fowler, C.E.
Roof of Cremorne Music Hall.....	16	Mr. William Humber, C.E.
Bridge over G. N. Railway	17	Mr. Joseph Cubitt, C.E.
Roof of Station—Dutch Rhenish Railway ..	18 and 19	Mr. Euschedi, C.E.
Bridge over the Thames—West London Extension Railway	20 to 24	Mr. William Baker, C.E.
Armour Plates	25	Mr. James Chalmers, C.E.
Suspension Bridge, Thames.....	26 to 29	Mr. Peter W. Barlow, C.E.
The Allen Engine	30	Mr. G. T. Porter, M.E.
Suspension Bridge, Avon	31 to 33	Mr. John Hawkshaw, C.E. and W. H. Barlow, C.E.
Underground Railway	34 to 36	Mr. John Fowler, C.E.

With copious Descriptive Letterpress, Specifications, &c.

"Handsomely lithographed and printed. It will find favour with many who desire to preserve in a permanent form copies of the plans and specifications prepared for the guidance of the contractors for many important engineering works."—*Engineer.*

"The large plates illustrating the works which have been selected by the Editor for the first examples of modern engineering progress are well executed, and the text is devoted to the specifications issued by the Engineers, and upon which the tenders for the execution of the works were based."—*Artizan.*

Humber's Great Work on Bridge Construction.

A COMPLETE and PRACTICAL TREATISE on CAST and WROUGHT-IRON BRIDGE CONSTRUCTION, including Iron Foundations. In Three Parts—Theoretical, Practical, and Descriptive. By WILLIAM HUMBER, Assoc. Inst. C.E., and M. Inst. M.E. Third Edition, revised and much improved, with 115 Double Plates (20 of which now first appear in this edition), and numerous additions to the Text. In 2 vols. imp. 4to., price 6*l.* 16*s.* 6*d.* half-bound in morocco. [*Just ready.*

"A very valuable contribution to the standard literature of civil engineering. In addition to elevations, plans, and sections, large scale details are given, which very much enhance the instructive worth of these illustrations. No engineer would willingly be without so valuable a fund of information.—*Civil Engineer and Architect's Journal.*

"The First or Theoretical Part contains mathematical investigations of the principles involved in the various forms now adopted in bridge construction. These investigations are exceedingly complete, having evidently been very carefully considered and worked out to the utmost extent that can be desired by the practical man. The tables are of a very useful character, containing the results of the most recent experiments, and amongst them are some valuable tables of the weight and cost of cast and wrought-iron structures actually erected. The volume of text is amply illustrated by numerous woodcuts, plates, and diagrams: and the plates in the second volume do great credit to both draughtsmen and engravers. In conclusion, we have great pleasure in cordially recommending this work to our readers."—*Artizan.*

"Mr. Humber's stately volumes lately issued—in which the most important bridges erected during the last five years, under the direction of the late Mr. Brunel, Sir W. Cubitt, Mr. Hawkshaw, Mr. Page, Mr. Fowler, Mr. Hemans, and others among our most eminent engineers, are drawn and specified in great detail."—*Engineer.*

Weale's Engineer's Pocket-Book.

THE ENGINEER'S, ARCHITECT'S, and CONTRACTOR'S POCKET-BOOK (LOCKWOOD & Co.'s; formerly WEALE'S). Published Annually. In roan tuck, gilt edges, with 10 Copper-Plates and numerous Woodcuts. Price 6*s.*

"There is no work published by or without authority, for the use of the scientific branches of the services, which contains anything like the amount of admirably arranged, reliable, and useful information. It is really a most solid, substantial, and excellent work; and not a page can be opened by a man of ordinary intelligence which will not satisfy him that this praise is amply deserved."—*Army and Navy Gazette.*

"A vast amount of really valuable matter condensed into the small dimensions of a book which is, in reality, what it professes to be—a pocket-book. . . . . We cordially recommend the book to the notice of the managers of coal and other mines; to them it will prove a handy book of reference on a variety of subjects more or less intimately connected with their profession. It might also be placed with advantage in the hands of the subordinate officers in collieries."—*Colliery Guardian.*

"The assignment of the late Mr. Weale's '*Engineer's Pocket-Book*' to Messrs. Lockwood & Co. has by no means lowered the standard value of the work. It is too well known among those for whom it is specially intended, to need more from us than the observation that this continuation of Mr. Weale's series of Pocket Books well sustains the reputation the work has so long enjoyed. Every branch of engineering is treated of, and facts, figures, and data of every kind abound."—*Mechanics' Mag.*

"It contains a large amount of information peculiarly valuable to those for whose use it is compiled. We cordially commend it to the engineering and architectural professions generally."—*Mining Journal.*

"A multitude of useful tables, without reference to which the engineer, architect, or contractor could scarcely get through a single day's work."—*Scientific Review.*

Barlow on the Strength of Materials, enlarged.

A TREATISE ON THE STRENGTH OF MATERIALS, with Rules for application in Architecture, the Construction of Suspension Bridges, Railways, &c.; and an Appendix on the Power of Locomotive Engines, and the effect of Inclined Planes and gradients. By PETER BARLOW, F.R.S., Mem. Inst. of France; of the Imp. and Royal Academies of St. Petersburgh and Brussels; of the Amer. Soc. Arts; and Hon. Mem. Inst. Civil Engineers. A New and considerably Enlarged Edition, revised by his Sons, P. W. BARLOW, F.R.S., Mem. Inst. C.E., and W. H. BARLOW, F.R.S., Mem. of Council Inst. C.E., to which are added a Summary of Experiments by EATON HODGKINSON, F.R.S., WILLIAM FAIRBAIRN, F.R.S., and DAVID KIRKALDY; an Essay (with Illustrations) on the effect produced by passing Weights over Elastic Bars, by the Rev. ROBERT WILLIS, M.A., F.R.S. And Formulæ for Calculating Girders, &c. The whole arranged and edited by WILLIAM HUMBER, Assoc. Inst. C.E., and Mem. Inst. M.E., Author of "A Complete and Practical Treatise on Cast and Wrought-Iron Bridge Construction," &c. &c. Demy 8vo, 400 pp., with 19 large Plates, and numerous woodcuts, price 18*s.* cloth.

Opinions of the Press.

"This edition has undergone considerable improvement, and has been brought down to the present date. It is one of the first books of reference in existence."—*Artizan.*

"Although issued as the sixth edition, the volume under consideration is worthy of being regarded, for all practical purposes, as an entirely new work . . . the book is undoubtedly worthy of the highest commendation, and of an honourable place in the library of every engineer."—*Mining Journal.*

"An increased value has been given to this very valuable work by the addition of a large amount of information, which cannot prove otherwise than highly useful to those who require to consult it. . . . . The arrangement and editing of this mass of information has been undertaken by Mr. Humber, who has most ably fulfilled a task requiring special care and ability to render it a success, which this edition most certainly is. He has given the finishing touch to the volume by introducing into it an interesting memoir of Professor Barlow, which tribute of respect, we are sure, will be appreciated by the members of the engineering profession."—*Mechanics' Magazine.*

"A work which should be well studied by every engineer. . . . A book which no engineer of any kind can afford to be without. In its present form its former value is much increased."—*Colliery Guardian.*

"The best book on the subject which has yet appeared. . . . . We know of no work that so completely fulfils its mission. . . . . As a scientific work of the first class, it deserves a foremost place on the bookshelves of every civil engineer and practical mechanic."—*English Mechanic.*

"There is not a pupil in an engineering school, an apprentice in an engineer's or architect's office, or a competent clerk of works, who will not recognise in the scientific volume newly given to circulation, an old and valued friend. . . So far as the strength of timber is concerned, there is no greater authority than Barlow."—*Building News.*

"It is scarcely necessary for us to make any comment upon the first portion of the new volume. . . . . Valuable alike to the student tyro, and experienced practitioner, it will always rank in future, as it has hitherto done, as the standard treatise upon this particular subject."—*Engineer.*

"The present edition offers some important advantages over previous ones. The additions are both extensive and valuable, comprising experiments by Hodgkinson on the strength of cast-iron; extracts from papers on the transverse strength of beams by W. H. Barlow; an article on the strength of columns; experiments by Fairbairn, on iron and steel plates, on the behaviour of girders subjected to the vibration of a changing load, and on various cast and wrought-iron beams; experiments by Kirkaldy, on wrought-iron and steel bars, and a short appendix of formulæ for ready application in computing the strains on bridges."—*Engineering.*

Strains, Formulæ & Diagrams for Calculation of.

A HANDY BOOK for the CALCULATION of STRAINS in GIRDERS and SIMILAR STRUCTURES, and their STRENGTH; consisting of Formulæ and Corresponding Diagrams, with numerous Details for Practical Application, &c. By WILLIAM HUMBER, Assoc. Inst. C.E., &c., Author of "A Record of the Progress of Modern Engineering," &c. &c. Fcap. 8vo, with nearly 100 Woodcuts and 3 Plates, price 7*s.* 6*d.* cloth. [*Recently published.*

It is hoped that a small work, in a handy form, devoted entirely to Bridge and Girder Calculations, without giving more than is absolutely necessary for the complete solution of practical problems, will meet with ready acceptance from the engineering profession. One of the chief features of the present work is the extensive application of simply constructed DIAGRAMS *to the calculation of the strains on bridges and girders.*

"To supply a universally recognised want of simple formulæ, applicable to the varied problems to be met with in ordinary practice, Mr. Humber, whose works on modern engineering afford sufficient evidence of his qualifications for the task, has compiled his 'Handy Book.' The arrangement of the matter in this little volume is as convenient as it well could be. . . . . The system of employing diagrams as a substitute for complex computations is one justly coming into great favour, and in that respect Mr. Humber's volume is fully up to the times."—*Engineering.*

"The formulæ are neatly expressed, and the diagrams good."—*Athenæum.*

"That a necessity existed for the book is evident, we think; that Mr. Humber has achieved his design is equally evident. . . . . We heartily commend the really *handy* book to our engineer and architect readers."—*English Mechanic.*

"It is, in fact, what its name indicates, a *handy book*, ... giving no more than is absolutely necessary for the complete solution of practical problems."—*Colliery Guardian.*

"This capital little work will supply a want, often found by engineers, viz., of having the requisite formulæ for calculating strains in a complete form, and yet sufficiently portable to be carried in the pocket. . . . . Almost every formula that could possibly be required, together with diagrams of strains, is put concisely, yet clearly, in a work of considerably less size than an engineering pocket book."—*Artizan.*

Strains.

THE STRAINS ON STRUCTURES OF IRONWORK; with Practical Remarks on Iron Construction. By F. W. SHEILDS, M. Inst. C.E. Second Edition, with 5 plates. Royal 8vo, 5*s.* cloth.

CONTENTS.—Introductory Remarks; Beams Loaded at Centre; Beams Loaded at unequal distances between supports; Beams uniformly Loaded; Girders with triangular bracing Loaded at centre; Ditto, Loaded at unequal distances between supports; Ditto, uniformly Loaded; Calculation of the Strains on Girders with triangular Basings; Cantilevers; Continuous Girders; Lattice Girders; Girders with Vertical Struts and Diagonal Ties; Calculation of the Strains on Ditto; Bow and String Girders; Girders of a form not belonging to any regular figure; Plate Girders; Apportionments of Material to Strain; Comparison of different Girders; Proportion of Length to Depth of Girders; Character of the Work; Iron Roofs.

Trigonometrical Surveying.

AN OUTLINE OF THE METHOD OF CONDUCTING A TRIGONOMETRICAL SURVEY, for the Formation of Geographical and Topographical Maps and Plans, Military Reconnaissance, Levelling, &c., with the most useful Problems in Geodesy and Practical Astronomy, and Formulæ and Tables for Facilitating their Calculation. By MAJOR-GENERAL FROME, R.E., Inspector-General of Fortifications, &c. Third Edition, revised and improved. With 10 Plates and 113 Woodcuts. Royal 8vo, 12*s.* cloth.

Hydraulics.

HYDRAULIC TABLES, CO-EFFICIENTS, and FORMULÆ for finding the Discharge of Water from Orifices, Notches, Weirs, Pipes, and Rivers. By JOHN NEVILLE, Civil Engineer, M.R.I.A. Second Edition, with extensive Additions, New Formulæ, Tables, and General Information on Rain-fall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. With numerous Woodcuts, 8vo, 16*s.* cloth.

*** This work contains a vast number of different hydraulic formulæ, and the most extensive and accurate tables yet published for finding the mean velocity of discharge from triangular, quadrilateral, and circular orifices, pipes, and rivers; with experimental results and co-efficients; effects of friction; of the velocity of approach; and of curves, bends, contractions, and expansions; the best form of channel; the drainage effects of long and short weirs, and weir-basins; extent of back-water from weirs; contracted channels; catchment-basins; hydrostatic and hydraulic pressure; water-power, &c. &c.

Levelling.

A TREATISE on the PRINCIPLES and PRACTICE of LEVELLING; showing its Application to Purposes of Railway and Civil Engineering, in the Construction of Roads; with Mr. TELFORD'S Rules for the same. By FREDERICK W. SIMMS, F.G.S., M. Inst. C.E. Fifth Edition, very carefully revised, with the addition of Mr. LAW'S Practical Examples for Setting out Railway Curves, and Mr. TRAUTWINE'S Field Practice of Laying out Circular Curves. With 7 Plates and numerous Woodcuts. 8vo, 8*s.* 6*d.* cloth. *** TRAUTWINE on Curves, separate, price 5*s.*

"One of the most important text-books for the general surveyor, and there is scarcely a question connected with levelling for which a solution would be sought but that would be satisfactorily answered by consulting the volume."—*Mining Journal.*

"The text-book on levelling in most of our engineering schools and colleges."—*Engineer.*

"The publishers have rendered a substantial service to the profession, especially to the younger members, by bringing out the present edition of Mr. Simms's useful work."—*Engineering.*

Tunnelling.

PRACTICAL TUNNELLING; explaining in Detail the Setting out of the Works; Shaft Sinking and Heading Driving; Ranging the Lines and Levelling Under-Ground; Sub-Excavating, Timbering, and the construction of the Brickwork of Tunnels; with the Amount of Labour required for, and the Cost of the various Portions of the Work. By FREDK. W. SIMMS, F.R.A.S., F.G.S., M. Inst. C.E., Author of "A Treatise on the Principles and Practice of Levelling," &c. &c. Second Edition, revised by W. DAVIS HASKOLL, Civil Engineer, Author of "The Engineer's Field-Book," &c. &c. With 16 large folding Plates and numerous Woodcuts. Imperial 8vo, 1*l.* 1*s.* cloth.

Strength of Cast Iron, &c.

A PRACTICAL ESSAY on the STRENGTH of CAST IRON and OTHER METALS; intended for the Assistance of Engineers, Iron-Masters, Millwrights, Architects, Founders, Smiths, and others engaged in the Construction of Machines, Buildings, &c.; containing Practical Rules, Tables, and Examples, founded on a series of New Experiments; with an Extensive Table of the Properties of Materials. By the late THOMAS TREDGOLD, Mem. Inst. C.E., Author of "Elementary Principles of Carpentry," "History of the Steam-Engine," &c. Fifth Edition, much improved. Edited by EATON HODGKINSON, F.R.S.; to which are added EXPERIMENTAL RESEARCHES on the STRENGTH and OTHER PROPERTIES of CAST IRON; with the Development of New Principles, Calculations Deduced from them, and Inquiries Applicable to Rigid and Tenacious Bodies generally. By the EDITOR. The whole Illustrated with 9 Engravings and numerous Woodcuts. 8vo, 12*s.* cloth.

*** HODGKINSON'S EXPERIMENTAL RESEARCHES ON THE STRENGTH AND OTHER PROPERTIES OF CAST IRON may be had separately. With Engravings and Woodcuts. 8vo, price 6*s.* cloth.

The High-Pressure Steam Engine.

THE HIGH-PRESSURE STEAM ENGINE; an Exposition of its Comparative Merits, and an Essay towards an Improved System of Construction, adapted especially to secure Safety and Economy. By Dr. ERNST ALBAN, Practical Machine Maker, Plau, Mecklenberg. Translated from the German, with Notes, by Dr. POLE, F.R.S., M. Inst. C.E., &c. &c. With 28 fine Plates, 8vo, 16*s.* 6*d.* cloth.

"A work like this, which goes thoroughly into the examination of the high-pressure engine, the boiler, and its appendages, &c., is exceedingly useful, and deserves a place in every scientific library."—*Steam Shipping Chronicle.*

Tables of Curves.

TABLES OF TANGENTIAL ANGLES and MULTIPLES for setting out Curves from 5 to 200 Radius. By ALEXANDER BEAZELEY, M. Inst. C.E. Printed on 48 Cards, and sold in a cloth box, waistcoat-pocket size, price 3*s.* 6*d.*

"Each table is printed on a small card, which, being placed on the theodolite, leaves the hands free to manipulate the instrument—no small advantage as regards the rapidity of work. They are clearly printed, and compactly fitted into a small case for the pocket—an arrangement that will recommend them to all practical men."—*Engineer.*

"Very handy: a man may know that all his day's work must fall on two of these cards, which he puts into his own card-case, and leaves the rest behind."—*Athenæum.*

Laying Out Curves.

THE FIELD PRACTICE of LAYING OUT CIRCULAR CURVES for RAILROADS. By JOHN C. TRAUTWINE, C.E., of the United States (extracted from SIMMS's Work on Levelling). 8vo, 5*s.* sewed.

Surveying (Land and Marine).

LAND AND MARINE SURVEYING, in Reference to the Preparation of Plans for Roads and Railways, Canals, Rivers, Towns' Water Supplies, Docks and Harbours; with Description and Use of Surveying Instruments. By W. DAVIS HASKOLL, C.E., Author of "The Engineer's Field Book," "Examples of Bridge and Viaduct Construction," &c. Demy 8vo, price 12*s.* 6*d.* cloth, with 14 folding Plates, and numerous Woodcuts.

"'Land and Marine Surveying' is a most useful and well arranged book for the aid of a student. . . . . We can strongly recommend it as a carefully-written and valuable text-book."—*Builder*, July 14, 1868.

"So far as the general get-up of the work is concerned, it is much superior to either of its predecessors ('The Practice of Engineering Field Work,' 2 vols.); the lettering and figuring of the plans annexed to it are clear and intelligible, and its moderate price will not fail to be a recommendation."—*Engineer*, June 19, 1868.

"He only who is master of his subject can present it in such a way as to make it intelligible to the meanest capacity. It is in this that Mr. Haskoll excels. He has knowledge and experience, and can so give expression to it as to make any matter on which he writes, clear to the youngest pupil in a surveyor's office. . . . . The work will be found a useful one to men of experience, for there are few such who will not get some good ideas from it; but it is indispensable to the young practitioner."—*Colliery Guardian*, May 9, 1868.

"A volume which cannot fail to prove of the utmost practical utility. . . . . It is one which may be safely recommended to all students who aspire to become clean and expert surveyors; and from the exhaustive manner in which Mr. Haskoll has placed his long experience at the disposal of his readers, there will henceforth be no excuse for the complaint that young practitioners are at a disadvantage, through the neglect of their seniors to point out the importance of minute details, since they can readily supply the deficiency by the study of the volume now under consideration."—*Mining Journal*, May 5, 1868.

"A very useful and thoroughly practical treatise. . . . . We can confidently recommend this work to the engineering student."—*Artizan*, July, 1868.

Engineer's Office Almanack & Pocket Companion.

THE ENGINEER'S AND CONTRACTOR'S OFFICE ALMANACK AND POCKET COMPANION, containing, besides the usual Calendar and other Almanack information, Memoranda relating to Standing Orders, Railway Construction Regulations, Mensuration, Data and Formulæ for Wrought-Iron Girders, Steam Engines, Railways, Cranes, Roofs, Mill-Gearing, Hydraulics, Weight of Iron, &c. Published annually, with Ruled Paper for Memoranda, strongly bound in cloth, price 1*s.*

"Here are 48 well-filled pages of that kind of matter which is in most constant reference by engineers and contractors. . . . . We have checked many of the formulæ, and find them to have been selected from the latest and best authorities."—*Engineering*.

"Its contents are of the most handy kind, solving in a rapid manner many a problem of daily occurrence with engineers."—*English Mechanic*.

"The mechanical engineer, the hydraulic engineer, the builder, and railway and mining engineer will, each and all, find occasion throughout the year of referring to this Almanack."—*Colliery Guardian*.

"Undoubtedly the most useful engineering almanack yet issued. It comprises information and formulæ upon almost every subject connected with practical engineering, upon which the man of business is likely to require to refresh his memory."—*Mining Journal*.

Fire Engineering.

FIRES, FIRE-ENGINES, AND FIRE BRIGADES. With a History of Manual and Steam Fire-Engines, their Construction, Use, and Management; Remarks on Fire-Proof Buildings, and the Preservation of Life from Fire; Statistics of the Fire Appliances in English Towns; Foreign Fire Systems; Hints for the formation of, and Rules for, Fire Brigades; and an Account of American Steam Fire-Engines. By CHARLES F. T. YOUNG, C.E., Author of "The Economy of Steam Power on Common Roads," &c. With numerous Illustrations, Diagrams, &c., handsomely printed, 544 pp., demy 8vo, price *1l.* 4*s.* cloth.

"A large well-filled and useful book upon a subject which possesses a wide and increasing public interest. . . . . To such of our readers as are interested in the subject of fires and fire apparatus we can most heartily commend this book. . . . . It is really the only English work we now have upon the subject."—*Engineering.*

"Mr. Young has proved by his present work that he is a good engineer, and possessed of sufficient literary energy to produce a very readable and interesting volume."—*Engineer.*

"Fire, above all the elements, is to be dreaded in a great city, and Mr. Young deserves hearty thanks for the elaborate pains, benevolent spirit, scientific knowledge, and lucid exposition he has brought to bear upon the subject; and his substantial book should meet with substantial success, for it concerns every one who has even a skin which is not fireproof."—*Illustrated London News.*

"A volume which must be regarded as the text-book of its subject, and which in point of interest and intrinsic value is second to no contribution to a special department of history with which we are acquainted. 'Fires, Fire-Engines, and Fire Brigades' is the production of an earnest and diligent writer who comes to the task he has undertaken with a thorough love of it, and a firm determination to do it justice. . . . . The style of the work is admirable. . . . . It has the surpassing merit of being thoroughly reliable."—*Insurance Record.*

"That Mr. Young's treatise is an exhaustive one will be admitted when we state that there does not appear to be anything within the scope of his comprehensive title that has been left unnoticed. An immense amount of the most varied information relating to the subject has been collected from every conceivable source, and goes to form a history full of abiding interest. Great credit is unquestionably due to Mr. Young for having brought before the public the results of his exploration in this hitherto untrodden field. We strongly recommend the book to the notice of all who are in any way interested in fires, fire-engines, or fire-brigades."—*Mechanics' Magazine.*

Earthwork, Measurement and Calculation of.

A MANUAL on EARTHWORK. By ALEX. J. S. GRAHAM, C.E., Resident Engineer, Forest of Dean Central Railway. With numerous Diagrams. 18mo, *2s.* 6*d.* cloth.

"We can cordially recommend the work to the notice of our readers."—*Building News.*

"As a really handy book for reference, we know of no work equal to it; and the railway engineers and others employed in the measurement and calculation of earthwork will find a great amount of practical information very admirably arranged, and available for general or rough estimates, as well as for the more exact calculations required in the engineers' contractor's offices."—*Artizan.*

"The object of this little book is an investigation of all the principles requisite for the measurement and calculation of earthworks, and a consideration of the data necessary for such operations. The author has evidently bestowed much care in effecting this object, and points out with much clearness the results of his own observations, derived from practical experience. The subjects treated of are accompanied by well-executed diagrams and instructive examples."—*Army and Navy Gazette.*

Field-Book for Engineers.

THE ENGINEER'S, MINING SURVEYOR'S, and CONTRACTOR'S FIELD-BOOK. By W. DAVIS HASKOLL, Civil Engineer. Second Edition, much enlarged, consisting of a Series of Tables, with Rules, Explanations of Systems, and Use of Theodolite for Traverse Surveying and Plotting the Work with minute accuracy by means of Straight Edge and Set Square only; Levelling with the Theodolite, Casting out and Reducing Levels to Datum, and Plotting Sections in the ordinary manner; Setting out Curves with the Theodolite by Tangential Angles and Multiples with Right and Left-hand Readings of the Instrument; Setting out Curves without Theodolite on the System of Tangential Angles by Sets of Tangents and Offsets; and Earthwork Tables to 80 feet deep calculated for every 6 inches in depth. With numerous wood-cuts, 12mo, price 12*s.* cloth.

"A very useful work for the practical engineer and surveyor. Every person engaged in engineering field operations will estimate the importance of such a work and the amount of valuable time which will be saved by reference to a set of reliable tables prepared with the accuracy and fullness of those given in this volume."—*Railway News.*

"The book is very handy, and the author might have added that the separate tables of sines and tangents to every minute will make it useful for many other purposes, the genuine traverse tables existing all the same."—*Athenæum.*

"The work forms a handsome pocket volume, and cannot fail, from its portability and utility, to be extensively patronised by the engineering profession."—*Mining Journal.*

"We know of no better field-book of reference or collection of tables than that Mr. Haskoll has given."—*Artizan.*

"A series of tables likely to be very useful to many civil engineers."—*Building News.*

"A very useful book of tables for expediting field-work operations. . . . The present edition has been much enlarged."—*Mechanics' Magazine.*

"We strongly recommend this second edition of Mr. Haskoll's 'Field Book' to all classes of surveyors."—*Colliery Guardian.*

Railway Engineering.

THE PRACTICAL RAILWAY ENGINEER. A concise Description of the Engineering and Mechanical Operations and Structures which are combined in the Formation of Railways for Public Traffic; embracing an Account of the Principal Works executed in the Construction of Railways; with Facts, Figures, and Data, intended to assist the Civil Engineer in designing and executing the important details required. By G. DRYSDALE DEMPSEY, C.E. Fourth Edition, revised and greatly extended. With 71 double quarto Plates, 72 Woodcuts, and Portrait of GEORGE STEPHENSON. One large vol. 4to., 2*l.* 12*s.* 6*d.* cloth.

Harbours.

THE DESIGN and CONSTRUCTION of HARBOURS. By THOMAS STEVENSON, F.R.S.E., M.I.C.E. Reprinted and enlarged from the Article "Harbours," in the Eighth Edition of "The Encyclopædia Britannica." With 10 Plates and numerous Cuts. 8vo, 10*s.* 6*d.* cloth.

Bridge Construction in Masonry, Timber, and Iron.

EXAMPLES OF BRIDGE AND VIADUCT CONSTRUCTION OF MASONRY, TIMBER, AND IRON; consisting of 46 Plates from the Contract Drawings or Admeasurement of select Works. By W. DAVIS HASKOLL, C.E. Second Edition, with the addition of 554 Estimates, and the Practice of Setting out Works, illustrated with 6 pages of Diagrams. Imp. 4to, price *2l.* 12*s.* 6*d.* half-morocco.

"One of the very few works extant descending to the level of ordinary routine, and treating on the common every-day practice of the railway engineer. . . . A work of the present nature by a man of Mr. Haskoll's experience, must prove invaluable to hundreds. The tables of estimates appended to this edition will considerably enhance its value."—*Engineering.*

"We must express our cordial approbation of the work just issued by Mr. Haskoll. . . . . Besides examples of the best and most economical forms of bridge construction, the author has compiled a series of estimates which cannot fail to be of service to the practical man. . . . The examples of bridges are selected from those of the most notable construction on the different lines of the kingdom, and their details may consequently be safely followed."—*Railway News.*

"A very valuable volume, and may be added usefully to the library of every young engineer."—*Builder.*

"An excellent selection of examples, very carefully drawn to useful scales of proportion."—*Artizan.*

Mathematical and Drawing Instruments.

A TREATISE ON THE PRINCIPAL MATHEMATICAL AND DRAWING INSTRUMENTS employed by the Engineer, Architect, and Surveyor. By FREDERICK W. SIMMS, F.G.S., M. Inst. C.E., Author of "Practical Tunnelling," &c. &c. Third Edition, with a Description of the Theodolite, together with Instructions in Field Work, compiled for the use of Students on commencing practice. With numerous Cuts. 12mo, price 3*s.* 6*d.* cloth.

Oblique Arches.

A PRACTICAL TREATISE ON THE CONSTRUCTION of OBLIQUE ARCHES. By JOHN HART. Third Edition, with Plates. Imperial 8vo, price 8*s.* cloth.

*** *The small remaining stock of this work, which has been unobtainable for some time, has just been purchased by* LOCKWOOD & CO.

Oblique Bridges.

A PRACTICAL and THEORETICAL ESSAY on OBLIQUE BRIDGES, with 13 large folding Plates. By GEO. WATSON BUCK, M. Inst. C.E. Second Edition, corrected by W. H. BARLOW, M. Inst. C.E. Imperial 8vo, 12*s.* cloth.

"The standard text-book for all engineers regarding skew arches, is Mr. Buck's treatise, and it would be impossible to consult a better."—*Engineer.*

"A very complete treatise on the subject, re-edited by Mr. Barlow, who has added to it a method of making the requisite calculations without the use of trigonometrical formulæ."—*Builder.*

Rudimentary Works in Engineering, &c.

WEALE'S SERIES OF RUDIMENTARY WORKS IN ENGINEERING, ARCHITECTURE, MECHANICS, &c. &c. At prices varying from 1*s.* to 5*s.*

*** *The following are included in this excellent and cheap Series of Books (numbering upwards of 200 different Works in almost every department of Science, Art, &c.), a complete List of which may be had on application to* Messrs. LOCKWOOD & Co.

STEAM ENGINE. By DR. LARDNER. 1*s.*

TUBULAR AND IRON GIRDER BRIDGES, including the Britannia and Conway Bridges. By G. D. DEMPSEY. 1*s.* 6*d.*

STEAM BOILERS, their Construction and Management. By R. ARMSTRONG. With Additions by R. MALLET. 1*s.* 6*d.*

RAILWAY CONSTRUCTION. By SIR M. STEPHENSON. *New Edition*, 2*s.* 6*d.*

STEAM AND LOCOMOTION, on the Principle of connecting Science with Practice. By J. SEWELL. 2*s.*

THE LOCOMOTIVE ENGINE. By G. D. DEMPSEY. 1*s.* 6*d.*

ILLUSTRATIONS TO THE ABOVE. 4to. 4*s.* 6*d.*

STEAM ENGINE, Mathematical Theory of. By T. BAKER. 1*s.*

ENGINEER'S GUIDE TO THE ROYAL AND MERCANTILE NAVIES. By a Practical Engineer. Revised by D. F. MCCARTHY. 3*s.*

LIGHTHOUSES, their Construction and Illumination. By ALAN STEVENSON. 3*s.*

CRANES AND MACHINERY FOR RAISING HEAVY BODIES, the Art of Constructing. By J. GLYNN. 1*s.*

CIVIL ENGINEERING. By H. LAW and G. R. BURNELL. *New Edition*, 5*s.*

DRAINING DISTRICTS AND LANDS. By G. D. DEMPSEY. 1*s.* 6*d.* } The
DRAINING AND SEWAGE OF TOWNS AND BUILDINGS. By G. D. DEMPSEY. 2*s.* } 2 vols. in 1, 3*s.* 6*d.*

WELL-SINKING, BORING, AND PUMP WORK. By J. G. SWINDELL; Revised by G. R. BURNELL. 1*s.*

ROAD-MAKING AND MAINTENANCE OF MACADAMISED ROADS. By GEN. SIR J. BURGOYNE. 1*s.* 6*d.*

AGRICULTURAL ENGINEERING, BUILDINGS, MOTIVE POWERS, FIELD MACHINES, MACHINERY AND IMPLEMENTS. By G. H. ANDREWS, C.E. 3*s.*

ECONOMY OF FUEL. By T. S. PRIDEAUX. 1*s.* 6*d.*

EMBANKING LANDS FROM THE SEA. By J. WIGGINS. 2*s.*

WATER POWER, as applied to Mills, &c. By J. GLYNN. 2*s.*

A TREATISE ON GAS WORKS, AND THE PRACTICE OF MANUFACTURING AND DISTRIBUTING COAL GAS. By S. HUGHES, C.E. 3*s.*

WATERWORKS FOR THE SUPPLY OF CITIES AND TOWNS. By S. HUGHES, C.E. 3*s.*

SUBTERRANEOUS SURVEYING, AND THE MAGNETIC VARIATION OF THE NEEDLE. By T. FENWICK, with Additions by T. BAKER. 2*s.* 6*d.*

CIVIL ENGINEERING OF NORTH AMERICA. By D. STEVENSON. 3*s.*

HYDRAULIC ENGINEERING. By G. R. BURNELL. 3*s.*

RIVERS AND TORRENTS, with the Method of Regulating their Course and Channels, Navigable Canals, &c., from the Italian of PAUL FRISI. 2*s.* 6*d.*

COMBUSTION OF COAL AND THE PREVENTION OF SMOKE. By C. WYE WILLIAMS, M.I.C.E. 3*s.*

ARCHITECTURE.

Construction.

THE SCIENCE of BUILDING: an Elementary Treatise on the Principles of Construction. Especially adapted to the Requirements of Architectural Students. By E. WYNDHAM TARN, M.A., Architect. Illustrated with 47 Wood Engravings. Demy 8vo, price 8*s.* 6*d.* cloth. [*Just published.*

"No architectural student should be without this hand-book of constructional knowledge."—*Architect*, April 9, 1870.

"The book is very far from being a mere compilation; it is an able digest of information which is only to be found scattered through various works, and contains more really original writing than many putting forth far stronger claims to originality. . . . Mr. Tarn has done his work exceedingly well, and he has produced a book which ought to earn him the thanks of all architectural students. The book is clearly printed in bold type, the wood-cuts are all well executed, and the work is made of a very convenient size for reference."—*Engineering*, May 5, 1870.

"The quiet, neat, scientific appropriateness of the language employed, distinguishes the master mind."—*Mining Journal*, April 9, 1870.

Chambers' Civil Architecture, by Gwilt.

A TREATISE ON THE DECORATIVE PART of CIVIL ARCHITECTURE. By Sir WILLIAM CHAMBERS, K.P.S., F.R.S., F.S.A., F.R.S.S. With Illustrations, Notes, and an Examination of Grecian Architecture, by JOSEPH GWILT, F.S.A. New and Cheap Edition, revised and edited by W. H. LEEDS. With 65 Plates, and Portrait of the Author. Royal 4to, 1*l.* 1*s.* cloth.

*** *A new edition of this standard architectural work (which has already passed through several high-priced issues), so cheap as to place it within the reach of the humbler classes of students and practical men, and at the same time so carefully edited and well executed as to make it worthy of a place on the shelves of the more opulent, cannot fail to be received as a boon by the professional public.*

Villa Architecture.

A HANDY BOOK of VILLA ARCHITECTURE; being a Series of Designs for Villa Residences in various Styles. With Detailed Specifications and Estimates. By C. WICKES, Architect, Author of "The Spires and Towers of the Mediæval Churches of England," &c. First Series, consisting of 30 Plates; Second Series, 31 Plates. Complete in 1 vol., 4to, price 2*l.* 10*s.* half morocco. Either Series separate, price 1*l.* 7*s.* each, half morocco.

"The whole of the designs bear evidence of their being the work of an artistic architect, and they will prove very valuable and suggestive to architects, students, and amateurs."—*Building News.*

"Suburban builders, who are now so largely employed all round the metropolis, may get a few valuable hints by consulting Mr. Wickes's publication."—*Art Journal.*

"There is so much elegance and good taste manifested in these designs for villa residences, and so much practical knowledge is displayed in the accompanying working plans, that we have pleasure in recommending the work to the profession as well as to persons about to build."—*News of the World.*

The Young Architect's Book.

HINTS TO YOUNG ARCHITECTS; comprising Advice to those who, while yet at school, are destined to the Profession; to such as, having passed their pupilage, are about to travel; and to those who, having completed their education, are about to practise. By GEORGE WIGHTWICK, Architect, Author of "The Palace of Architecture," &c. &c. Second Edition. With numerous Woodcuts. 8vo, 7*s.*, extra cloth.

Drawing for Builders and Students.

PRACTICAL RULES ON DRAWING for the OPERATIVE BUILDER and YOUNG STUDENT in ARCHITECTURE. By GEORGE PYNE, Author of a "Rudimentary Treatise on Perspective for Beginners." With 14 Plates, 4to, 7*s.* 6*d.*, boards.

CONTENTS.—I. Practical Rules on Drawing—Outlines. II. Ditto—the Grecian and Roman Orders. III. Practical Rules on Drawing—Perspective. IV. Practical Rules on Light and Shade. V. Practical Rules on Colour, &c. &c.

Ventilation.

A TREATISE ON VENTILATION, NATURAL and ARTIFICIAL. By ROBERT RITCHIE, C.E., Author of "Railways, their Rise, Progress, and Construction," &c. &c. With numerous Plates and Woodcuts. 8vo, 8*s.* 6*d.* cloth.

"This must continue to be for some time the text-book upon one of the chief difficulties of domestic architectural construction and of social hygienics."—*Lancet.*

Cottages, Villas, and Country Houses.

DESIGNS and EXAMPLES of COTTAGES, VILLAS, and COUNTRY HOUSES; being the Studies of several eminent Architects and Builders; consisting of Plans, Elevations, and Perspective Views; with approximate Estimates of the Cost of each. In 4to, with 67 plates, price 1*l.* 1*s.*, cloth.

Weale's Builder's and Contractor's Price Book.

THE BUILDER'S AND CONTRACTOR'S PRICE BOOK (LOCKWOOD & CO.'S, formerly WEALE'S). Published Annually. Containing Prices for Work in all branches of the Building Trade, with Items numbered for easy reference, and an Appendix of Tables, Notes, and Memoranda, arranged to afford detailed information, commonly required in preparing Estimates, &c. Originally Edited by the late GEO. R. BURNELL, C.E., &c. 12mo, 4*s.*, cloth.

"A multitudinous variety of useful information for builders and contractors. . . . . With its aid the prices for all work connected with the building trade may be estimated."—*Building News.*

"Carefully revised, admirably arranged, and clearly printed, it offers at a glance a ready method of preparing an estimate or specification upon a basis that is unquestionable. A reliable book of reference in the event of a dispute between employer and employed."—*Engineer.*

"Well done and reliable. It is the duty of a just critic to point out where any improvement can be made in any work, but Mr. Burnell has anticipated all objections in his clearly-printed book. We therefore recommend it to all branches of the profession."—*English Mechanic.*

NAVAL ARCHITECTURE, &c.

Ship-Building and Steam Ships.

SHIP-BUILDING IN IRON AND WOOD. By ANDREW MURRAY, M.I.C.E., Chief Engineer and Inspector of Machinery of H.M.'s Dockyard, Portsmouth; and STEAM SHIPS, by ROBERT MURRAY, C.E., Engineer Surveyor to the Board of Trade. Second Edition. In 1 vol., 4to, with 28 Plates and numerous Woodcuts, price 14*s.* cloth.

"Indispensable in the office of the naval architect, whether employing wood or iron."—*Practical Mechanic's Journal.*

"Ought to be in the hands of every shipbuilder or shipwright."—*Sunderland Herald.*

Naval Architecture.

RUDIMENTS OF NAVAL ARCHITECTURE. Compiled for the Use of Beginners. By JAMES PEAKE, formerly of the School of Naval Architecture, H.M. Dockyard, Portsmouth. Third Edition, with many Illustrations. 12mo, cloth limp, price 3*s.*

Principles of Ship Construction.

ELEMENTARY AND PRACTICAL PRINCIPLES of the CONSTRUCTION OF SHIPS for OCEAN AND RIVER SERVICE. By HAKON A. SOMMERFELDT, Surveyor to the Royal Norwegian Navy. 12mo, cloth limp, price 1*s.*

*** ATLAS OF FIFTEEN PLATES to the above. 4to, price 7*s.* 6*d.*

Masting, Rigging of Ships, &c.

RUDIMENTARY TREATISE ON MASTING, MAST-MAKING, and RIGGING OF SHIPS. By ROBERT KIPPING, N.A. 10th Edition, Illustrated. 12mo, cloth limp, price 1*s.* 6*d.*

Sail-Making.

ELEMENTARY TREATISE ON SAIL-MAKING; with Draughting, and the Centre of Effort of the Sails. Also Weights and Sizes of Ropes, Masting, Rigging, and Sails of Steam Vessels, &c. By ROBERT KIPPING, N.A. Seventh Edition. With numerous Woodcuts. 12mo, cloth limp, price 2*s.* 6*d.*

Navigation, &c.

RUDIMENTARY TREATISE ON NAVIGATION; the Sailor's Sea-Book. In Two Parts. PART I.—How to Keep the Log and Work it off, &c. PART II.—On Finding the Latitude and Longitude. By JAMES GREENWOOD, Esq., B.A. Fifth Edition. With several Engravings and Illustrations (in colours) of the Flags of Maritime Nations. 12mo, cloth limp, price 2*s.*

Grantham's Iron Ship-Building, enlarged.

ON IRON SHIP-BUILDING; with Practical Examples and Details. Fifth Edition. Imp. 4to, boards, enlarged from 24 to 40 Plates (21 quite new), including the latest Examples. Together with separate Text, 12mo, cloth limp, also considerably enlarged, By JOHN GRANTHAM, M. Inst. C.E., &c. Price *2l. 2s.* complete.

Description of Plates.

1. Hollow and Bar Keels, Stem and Stern Posts.
2. Side Frames, Floorings, and Bilge [Pieces.
3. Floorings *continued*—Keelsons, Deck Beams, Gunwales, and Stringers.
4. Gunwales *continued*—Lower Decks, and Orlop Beams.
4*a*. Gunwales and Deck Beam Iron.
5. Angle-Iron, T Iron, Z Iron, Bulb Iron, as Rolled for Building.
6. Rivets, shown in section, natural size; Flush and Lapped Joints, with Single and Double Riveting.
7. Plating, three plans; Bulkheads and Modes of Securing them.
8. Iron Masts, with Longitudinal and Transverse Sections.
9. Sliding Keel, Water Ballast, Moulding the Frames in Iron Ship Building, Levelling Plates.
10. Longitudinal Section, and Half-breadth Deck Plan of Large Vessels on a reduced Scale.
11. Midship Sections of Three Vessels.
12. *Large Vessel*, showing Details—*Fore End* in Section, and End View, with Stern Post, Crutches, &c.
13. *Large Vessel*, showing Details—*After End* in Section, with End View, Stern Frame for Screw, and Rudder.
14. *Large Vessel*, showing Details—*Midship Section*, half breadth.
15. *Machines* for Punching and Shearing Plates and Angle-Iron, and for Bending Plates; Rivet Hearth.
15*a*. Beam-Bending Machine, Independent Shearing, Punching and Angle-Iron Machine.
15*b*. Double Lever Punching and Shearing Machine, arranged for cutting Angle and T Iron, with Dividing Table and Engine.
16. *Machines.*—Garforth's Riveting Machine, Drilling and Counter-Sinking Machine.
16*a*. Plate Planing Machine.
17. *Air Furnace* for Heating Plates and Angle-Iron: Various Tools used in Riveting and Plating.
18. *Gunwale*; Keel and Flooring; Plan for Sheathing with Copper.
18*a*. Grantham's Improved Plan of Sheathing Iron Ships with Copper.
19. Illustrations of the Magnetic Condition of various Iron Ships.
20. Gray's Floating Compass and Binnacle, with Adjusting Magnets, &c.
21. Corroded Iron Bolt in Frame of Wooden Ship; Jointing Plates.
22–4. *Great Eastern*—Longitudinal Sections and Half-breadth Plans—Midship Section, with Details—Section in Engine Room, and Paddle Boxes.
25–6. Paddle Steam Vessel of Steel.
27. *Scarbrough*—Paddle Vessel of Steel.
28–9. Proposed Passenger Steamer.
30. *Persian*—Iron Screw Steamer.
31. Midship Section of H.M. Steam Frigate, *Warrior*.
32. Midship Section of H.M. Steam Frigate, *Hercules*.
33. Stem, Stern, and Rudder of H.M. Steam Frigate, *Bellerophon*.
34. Midship Section of H.M. Troop Ship, *Serapis*.
35. Iron Floating Dock.

"An enlarged edition of an elaborately illustrated work."—*Builder*, July 11, 1868.

"This edition of Mr. Grantham's work has been enlarged and improved, both with respect to the text and the engravings being brought down to the present period . . . The practical operations required in producing a ship are described and illustrated with care and precision."—*Mechanics' Magazine*, July 17, 1868.

"A thoroughly practical work, and every question of the many in relation to iron shipping which admit of diversity of opinion, or have various and conflicting personal interests attached to them, is treated with sober and impartial wisdom and good sense. . . . . As good a volume for the instruction of the pupil or student of iron naval architecture as can be found in any language."—*Practical Mechanic's Journal*, August, 1868.

"A very elaborate work. . . . It forms a most valuable addition to the history of iron shipbuilding, while its having been prepared by one who has made the subject his study for many years, and whose qualifications have been repeatedly recognised, will recommend it as one of practical utility to all interested in shipbuilding."—*Army and Navy Gazette*, July 11, 1868.

CARPENTRY, TIMBER, &c.

Tredgold's Carpentry, new & enlarged Edition.

THE ELEMENTARY PRINCIPLES OF CARPENTRY: a Treatise on the Pressure and Equilibrium of Timber Framing, the Resistance of Timber, and the Construction of Floors, Arches, Bridges, Roofs, Uniting Iron and Stone with Timber, &c. To which is added an Essay on the Nature and Properties of Timber, &c., with Descriptions of the Kinds of Wood used in Building; also numerous Tables of the Scantlings of Timber for different purposes, the Specific Gravities of Materials, &c. By THOMAS TREDGOLD, C.E. Edited by PETER BARLOW, F.R.S. Fifth Edition, corrected and enlarged. With 64 Plates (11 of which now first appear in this edition), Portrait of the Author, and several Woodcuts. In 1 large vol., 4to, *2l. 2s.* extra cloth. [*Just published.*

"'Tredgold's Carpentry' ought to be in every architect's and every builder's library, and those who do not already possess it ought to avail themselves of the new issue."—*Builder*, April 9, 1870.

"A work whose monumental excellence must commend it wherever skilful carpentry is concerned. The Author's principles are rather confirmed than impaired by time, and, as now presented, combine the surest base with the most interesting display of progressive science. The additional plates are of great intrinsic value."—*Building News*, Feb. 25, 1870.

"'Tredgold's Carpentry' has ever held a high position, and the issue of the fifth edition, in a still more improved and enlarged form, will give satisfaction to a very large number of artisans who desire to raise themselves in their business, and who seek to do so by displaying a greater amount of knowledge and intelligence than their fellow-workmen. It is as complete a work as need be desired. To the superior workman the volume will prove invaluable; it contains treatises written in language which he will readily comprehend."—*Mining Journal*, Feb. 12, 1870.

Grandy's Timber Tables.

THE TIMBER IMPORTER'S, TIMBER MERCHANT'S, and BUILDER'S STANDARD GUIDE. By RICHARD E. GRANDY. Comprising:—An Analysis of Deal Standards, Home and Foreign, with comparative Values and Tabular Arrangements for Fixing Nett Landed Cost on Baltic and North American Deals, including all intermediate Expenses, Freight, Insurance, Duty, &c., &c.; together with Copious Information for the Retailer and Builder. 12mo, price *7s. 6d.* cloth.

"Everything it pretends to be: built up gradually, it leads one from a forest to a trenail, and throws in, as a makeweight, a host of material concerning bricks, columns, cisterns, &c.—all that the class to whom it appeals requires."—*English Mechanic.*

"The only difficulty we have is as to what is NOT in its pages. What we have tested of the contents, taken at random, is invariably correct."—*Illustrated Builder's Journal.*

Tables for Packing-Case Makers.

PACKING-CASE TABLES; showing the number of Superficial Feet in Boxes or Packing-Cases, from six inches square and upwards. Compiled by WILLIAM RICHARDSON, Accountant. Oblong 4to, cloth, price *3s. 6d.*

"Will save much labour and calculation to packing-case makers and those who use packing-cases."—*Grocer.* "Invaluable labour-saving tables."—*Ironmonger.*

Nicholson's Carpenter's Guide.

THE CARPENTER'S NEW GUIDE; or, BOOK of LINES for CARPENTERS: comprising all the Elementary Principles essential for acquiring a knowledge of Carpentry. Founded on the late PETER NICHOLSON'S standard work. A new Edition, revised by ARTHUR ASHPITEL, F.S.A., together with Practical Rules on Drawing, by GEORGE PYNE. With 74 Plates, 4to, *1l.* 1*s.* cloth.

Dowsing's Timber Merchant's Companion.

THE TIMBER MERCHANT'S AND BUILDER'S COMPANION; containing New and Copious Tables of the Reduced Weight and Measurement of Deals and Battens, of all sizes, from One to a Thousand Pieces, and the relative Price that each size bears per Lineal Foot to any given Price per Petersburgh Standard Hundred; the Price per Cube Foot of Square Timber to any given Price per Load of 50 Feet; the proportionate Value of Deals and Battens by the Standard, to Square Timber by the Load of 50 Feet; the readiest mode of ascertaining the Price of Scantling per Lineal Foot of any size, to any given Figure per Cube Foot. Also a variety of other valuable information. By WILLIAM DOWSING, Timber Merchant. Second Edition. Crown 8vo, 3*s.* cloth.

"Everything is as concise and clear as it can possibly be made. There can be no doubt that every timber merchant and builder ought to possess it, because such possession would, with use, unquestionably save a very great deal of time, and, moreover, ensure perfect accuracy in calculations. There is also another class besides these who ought to possess it; we mean all persons engaged in carrying wood, where it is requisite to ascertain its weight. Mr. Dowsing's tables provide an easy means of doing this. Indeed every person who has to do with wood ought to have it."—*Hull Advertiser.*

MECHANICS, &c.

Mechanic's Workshop Companion.

THE OPERATIVE MECHANIC'S WORKSHOP COMPANION, and THE SCIENTIFIC GENTLEMAN'S PRACTICAL ASSISTANT; comprising a great variety of the most useful Rules in Mechanical Science; with numerous Tables of Practical Data and Calculated Results. By W. TEMPLETON, Author of "The Engineer's, Millwright's, and Machinist's Practical Assistant." Ninth Edition, with the addition of Mechanical Tables for Operative Smiths, Millwrights, Engineers, &c.; together with several Useful and Practical Rules in Hydraulics and Hydrodynamics, a variety of Experimental Results, and an Extensive Table of Powers and Roots. 11 Plates. 12mo, 5*s.* bound.

"As a text-book of reference, in which mechanical and commercial demands are judiciously met, TEMPLETON'S COMPANION stands unrivalled."—*Mechanics' Magazine.*

"Admirably adapted to the wants of a very large class. It has met with great success in the engineering workshop, as we can testify; and there are a great many men who, in a great measure, owe their rise in life to this little work."—*Building News.*

Engineer's Assistant.

THE ENGINEER'S, MILLWRIGHT'S, and MACHINIST'S PRACTICAL ASSISTANT; comprising a Collection of Useful Tables, Rules, and Data. Compiled and Arranged, with Original Matter, by W. TEMPLETON, Author of "The Operative Mechanic's Workshop Companion." 4th Edition. 18mo, 2*s.* 6*d.* cloth.

"A perfect *vade mecum* for all who are practically engaged in mechanical pursuits. So much varied information compressed into so small a space, and published at a price which places it within the reach of the humblest mechanic, cannot fail to command the sale which it deserves. With the utmost confidence we stamp this book with the approbation of the 'Mechanics' Magazine,' and having done so, commend it to the attention of our readers."—*Mechanics' Magazine.*

"To a practical engineer it must be of incalculable value."—*Morning Herald.*

"This work contains, in a connected and convenient form, admirably arranged and lucidly explained, all the information likely to be immediately and lastingly useful to those whose interests it is designed to subserve."—*Manufacturer and Inventor.*

"Every mechanic should become the possessor of the volume, and a more suitable present to an apprentice to any of the mechanical trades could not possibly be made."—*Building News.*

Designing, Measuring, and Valuing.

THE STUDENT'S GUIDE to the PRACTICE of DESIGNING, MEASURING, and VALUING ARTIFICERS' WORKS; containing Directions for taking Dimensions, Abstracting the same, and bringing the Quantities into Bill, with Tables of Constants, and copious Memoranda for the Valuation of Labour and Materials in the respective Trades of Bricklayer and Slater, Carpenter and Joiner, Sawyer, Stonemason, Plasterer, Smith and Ironmonger, Plumber, Painter and Glazier, Paperhanger. With 43 Plates and Woodcuts. The measuring, &c., edited by EDWARD DOBSON, Architect and Surveyor. Second Edition, with the Additions on Design, by E. LACY GARBETT, Architect; together with Tables for Squaring and Cubing. In one vol., 8vo, 9*s.* extra cloth.

Superficial Measurement.

THE TRADESMAN'S GUIDE TO SUPERFICIAL MEASUREMENT. Tables calculated from 1 to 200 inches in length, by 1 to 108 inches in breadth. Particularly recommended to Architects, Surveyors, Engineers, Timber Merchants, Builders, Carpenters, Upholsterers, Coach Makers, Looking and Crown Glass Dealers, Painters, Stonemasons, &c. By JAMES HAWKINGS. Fcp. 3*s.* 6*d.* cloth.

Manufacture of Iron.

IRON: its History, Properties, and Processes of Manufacture. By WILLIAM FAIRBAIRN, C.E., LL.D., F.R.S., &c. With numerous Woodcuts. New Edition, revised and enlarged. 8vo, price 10*s.* 6*d.* cloth.

"A scientific work of the first class, whose chief merit lies in bringing the more important facts connected with iron into a small compass, and within the comprehension and the means of all persons engaged in its manufacture, sale, or use."—*Mechanics' Magazine.*

MATHEMATICS, &c.

Gregory's Practical Mathematics.

MATHEMATICS for PRACTICAL MEN; being a Commonplace Book of Pure and Mixed Mathematics. Designed chiefly for the Use of Civil Engineers, Architects, and Surveyors. Part I. PURE MATHEMATICS—comprising Arithmetic, Algebra, Geometry, Mensuration, Trigonometry, Conic Sections, Properties of Curves. Part II. MIXED MATHEMATICS—comprising Mechanics in general, Statics, Dynamics, Hydrostatics, Hydrodynamics, Pneumatics, Mechanical Agents, Strength of Materials. With an Appendix of copious Logarithmic and other Tables. By OLINTHUS GREGORY, LL.D., F.R.A.S. Enlarged by HENRY LAW, C.E. 4th Edition, carefully revised and corrected by J. R. YOUNG, formerly Professor of Mathematics, Belfast College; Author of "A Course of Mathematics," &c. With 13 Plates. Medium 8vo, *1l.* 1*s.* cloth.

"As a standard work on mathematics it has not been excelled."—*Artizan.*

"The engineer or architect will here find ready to his hand, rules for solving nearly every mathematical difficulty that may arise in his practice. As a moderate acquaintance with arithmetic, algebra, and elementary geometry is absolutely necessary to the proper understanding of the most useful portions of this book, the author very wisely has devoted the first three chapters to those subjects, so that the most ignorant may be enabled to master the whole of the book, without aid from any other. The rules are in all cases explained by means of examples, in which every step of the process is clearly worked out."—*Builder.*

"One of the most serviceable books to the practical mechanics of the country. . . . The edition of 1847 was fortunately entrusted to the able hands of Mr. Law, who revised it thoroughly, re-wrote many chapters, and added several sections to those which had been rendered imperfect by advanced knowledge. On examining the various and many improvements which he introduced into the work, they seem almost like a new structure on an old plan, or rather like the restoration of an old ruin, not only to its former substance, but to an extent which meets the larger requirements of modern times. . . . . In the edition just brought out, the work has again been revised by Professor Young. He has modernised the notation throughout, introduced a few paragraphs here and there, and corrected the numerous typographical errors which have escaped the eyes of the former Editor. The book is now as complete as it is possible to make it. . . . . We have carried our notice of this book to a greater length than the space allowed us justified, but the experiments it contains are so interesting, and the method of describing them so clear, that we may be excused for overstepping our limit. It is an instructive book for the student, and a Text-book for him who having once mastered the subjects it treats of, needs occasionally to refresh his memory upon them."—*Building News.*

The Metric System.

A SERIES OF METRIC TABLES, in which the British Standard Measures and Weights are compared with those of the Metric System at present in use on the Continent. By C. H. DOWLING, C. E. 8vo, 10*s.* 6*d.* strongly bound.

"Mr. Dowling's Tables, which are well put together, come just in time as a ready reckoner for the conversion of one system into the other."—*Athenæum.*

"Their accuracy has been certified by Professor Airy, the Astronomer Royal."—*Builder.*

"Resolution 8.—That advantage will be derived from the recent publication of Metric Tables, by C. H. Dowling, C.E."—*Report of Section F, British Association, Bath.*

Inwood's Tables, greatly enlarged and improved.

TABLES FOR THE PURCHASING of ESTATES, Freehold, Copyhold, or Leasehold; Annuities, Advowsons, &c., and for the Renewing of Leases held under Cathedral Churches, Colleges, or other corporate bodies; for Terms of Years certain, and for Lives; also for Valuing Reversionary Estates, Deferred Annuities, Next Presentations, &c., together with Smart's Five Tables of Compound Interest, and an Extension of the same to lower and Intermediate Rates. By WILLIAM INWOOD, Architect. The 18th edition, with considerable additions, and new and valuable Tables of Logarithms for the more Difficult Computations of the Interest of Money, Discount, Annuities, &c., by M. FÉDOR THOMAN, of the Société Crédit Mobilier of Paris. 12mo, 8*s.* cloth.

*** *This edition (the 18th) differs in many important particulars from former ones. The changes consist,* first, *in a more convenient and systematic arrangement of the original Tables, and in the removal of certain numerical errors which a very careful revision of the whole has enabled the present editor to discover; and* secondly, *in the extension of practical utility conferred on the work by the introduction of Tables now inserted for the first time. This new and important matter is all so much actually added to* INWOOD'S TABLES; *nothing has been abstracted from the original collection: so that those who have been long in the habit of consulting* INWOOD *for any special professional purpose will, as heretofore, find the information sought still in its pages.*

"Those interested in the purchase and sale of estates, and in the adjustment of compensation cases, as well as in transactions in annuities, life insurances, &c., will find the present edition of eminent service."—*Engineering.*

"More than half a century has elapsed since the first edition was published, yet 'Inwood's Tables' still maintain a most enviable reputation; and when it is considered that the new issue, the Eighteenth edition, has been enriched by large additional contributions by Mr. Fédor Thoman, of the French Crédit Mobilier, whose carefully arranged tables of logarithms for the more difficult computations of the interest of money, discount, annuities, &c., cannot fail to be of the utmost utility, its value will be appreciated. The introduction contains an admirable epitome of the principles of decimals, and an explanation of all that is necessary to render the elaborate tables in the book of thorough utility to all consulting it. This new edition will certainly be referred to with quite as much confidence as its predecessors."—*Mining Journal.*

Compound Interest and Annuities.

THEORY of COMPOUND INTEREST and ANNUITIES; with Tables of Logarithms for the more Difficult Computations of Interest, Discount, Annuities, &c., in all their Applications and Uses for Mercantile and State Purposes. With an elaborate Introduction. By FÉDOR THOMAN, of the Société Crédit Mobilier, Paris. 12mo, cloth, 5*s.*

"A very powerful work, and the Author has a very remarkable command of his subject."—*Professor A. de Morgan.*

"No banker, merchant, tradesman, or man of business, ought to be without Mr. Thoman's truly 'handy-book.'"—*Review.*

"The author of this 'handy-book' deserves our thanks."—*Insurance Gazette.*

"We recommend it to the notice of actuaries and accountants."—*Athenæum.*

SCIENCE AND ART.

The Military Sciences.

AIDE-MÉMOIRE to the MILITARY SCIENCES. Framed from Contributions of Officers and others connected with the different Services. Originally edited by a Committee of the Corps of Royal Engineers. Second Edition, most carefully revised by an Officer of the Corps, with many additions; containing nearly 350 Engravings and many hundred Woodcuts. 3 vols. royal 8vo, extra cloth boards, and lettered, price 4*l.* 10*s.*

"A compendious encyclopædia of military knowledge, to which we are greatly indebted."—*Edinburgh Review.*

"The most comprehensive work of reference to the military and collateral sciences. Among the list of contributors, some seventy-seven in number, will be found names of the highest distinction in the services. . . . The work claims and possesses the great merit that by far the larger portion of its subjects have been treated originally by the practical men who have been its contributors."—*Volunteer Service Gazette.*

Field Fortification.

A TREATISE on FIELD FORTIFICATION, the ATTACK of FORTRESSES, MILITARY, MINING, and RECONNOITRING. By Colonel I. S. MACAULAY, late Professor of Fortification in the Royal Military Academy, Woolwich. Sixth Edition, crown 8vo, cloth, with separate Atlas of 12 Plates, sewed, price 12*s.* complete. [*Recently published.*

Dye-Wares and Colours.

THE MANUAL of COLOURS and DYE-WARES: their Properties, Applications, Valuation, Impurities, and Sophistications. For the Use of Dyers, Printers, Dry Salters, Brokers, &c. By J. W. SLATER. Post 8vo, cloth. [*Nearly Ready.*

*** *The object of this Manual is to furnish, in brief space, an account of the chemical products and natural wares used in dyeing, printing, and the accessory arts, their properties, their applications, the means of ascertaining their respective values, and of detecting the impurities which may be present.*

Electricity.

A MANUAL of ELECTRICITY; including Galvanism, Magnetism, Diamagnetism, Electro-Dynamics, Magno-Electricity, and the Electric Telegraph. By HENRY M. NOAD, Ph.D., F.C.S., Lecturer on Chemistry at St. George's Hospital. Fourth Edition, entirely rewritten. Illustrated by 500 Woodcuts. 8vo, 1*l.* 4*s.* cloth.

"This publication fully bears out its title of 'Manual.' It discusses in a satisfactory manner electricity, frictional and voltaic, thermo-electricity, and electro-physiology."—*Athenæum.*

"The commendations already bestowed in the pages of the *Lancet* on the former editions of this work are more than ever merited by the present. The accounts given of electricity and galvanism are not only complete in a scientific sense, but, which is a rarer thing, are popular and interesting."—*Lancet.*

Text-Book of Electricity.

THE STUDENT'S TEXT-BOOK OF ELECTRICITY: including Magnetism, Voltaic Electricity, Electro-Magnetism, Diamagnetism, Magneto-Electricity, Thermo-Electricity, and Electric Telegraphy. Being a Condensed Résumé of the Theory and Application of Electrical Science, including its latest Practical Developments, particularly as relating to Aërial and Submarine Telegraphy. By HENRY M. NOAD, Ph.D., Lecturer on Chemistry at St. George's Hospital. Post 8vo, 400 Illustrations, 12*s.* 6*d.* cloth.

*** *In carrying out the design of this work, the author has availed himself both of the matter* (*in a condensed form*) *and of the illustrations of his* "Manual of Electricity;" *but the present volume will be found to contain much additional and important information,* (*with many new illustrations,*) *which has become available since the publication of his larger work.*

"We can recommend Dr. Noad's book for clear style, great range of subject, a good index, and a plethora of woodcuts. Such collections as the present are indispensable."—*Athenæum.*

"A most elaborate compilation of the facts of electricity and magnetism, and of the theories which have been advanced concerning them."—*Popular Science Review.*

"Clear, compendious, compact, well illustrated, and well printed, this is an excellent manual."—*Lancet.*

"We can strongly recommend the work, as an admirable text-book, to every student—beginner or advanced—of electricity."—*Engineering.*

"The most complete manual on the subject of electricity to be met with."—*Observer.*

"Nothing of value has been passed over, and nothing given but what will lead to a correct, and even an exact, knowledge of the present state of electrical science."—*Mechanics' Magazine.*

"We know of no book on electricity containing so much information on experimental facts as this does, for the size of it, and no book of any size that contains so complete a range of facts."—*English Mechanic.*

Chemical Analysis.

THE COMMERCIAL HANDBOOK of CHEMICAL ANALYSIS; or Practical Instructions for the determination of the Intrinsic or Commercial Value of Substances used in Manufactures, in Trades, and in the Arts. By A. NORMANDY, Author of "Practical Introduction to Rose's Chemistry," and Editor of Rose's "Treatise of Chemical Analysis." Illustrated with Woodcuts. Second and cheaper Edition, post 8vo, 9*s.* cloth.

"We recommend this book to the careful perusal of every one; it may be truly affirmed to be of universal interest, and we strongly recommend it to our readers as a guide, alike indispensable to the housewife as to the pharmaceutical practitioner."—*Medical Times.*

"A volume of surpassing interest, in which the Author describes the character and properties of 400 different articles of commerce, the substances by which they are too frequently adulterated, and the means of their detection."—*Mining Journal.*

"The very best work on the subject the English press has yet produced."—*Mechanics' Magazine.*

Practical Philosophy.

A SYNOPSIS of PRACTICAL PHILOSOPHY. By the Rev. JOHN CARR, M.A., late Fellow of Trin. Coll., Cambridge. Second Edition. 18mo, 5*s.* cloth.

Science and Art.

THE YEAR-BOOK of FACTS in SCIENCE and ART; exhibiting the most important Improvements and Discoveries of the Past Year in Mechanics and the Useful Arts, Natural Philosophy, Electricity, Chemistry, Zoology and Botany, Geology and Mineralogy, Meteorology and Astronomy. By JOHN TIMBS, F.S.A., Author of "Curiosities of Science," "Things not Generally Known," &c. With Steel Portrait and Vignette. Fcap. 5*s.* cloth.

*** *This work, published annually, records the proceedings of the principal scientific societies, and is indispensable to all who wish to possess a faithful record of the latest novelties in science and the arts.*

The back Volumes, from 1861 to 1869, each containing a Steel Portrait, and an extra Volume for 1862, with Photograph, may still be had, price 5*s.* each.

"Persons who wish for a concise annual summary of important scientific events will find their desire in the 'Year Book of Facts.'"—*Athenæum.*

"The standard work of its class. Mr. Timbs's 'Year Book' is always full of suggestive and interesting matter, and is an excellent *résumé* of the year's progress in the sciences and the arts."—*Builder.*

"A correct exponent of scientific progress . . . . a record of abiding interest. If anyone wishes to know what progress science has made, or what has been done in any branch of art during the past year, he has only to turn to Mr. Timbs's pages, and is sure to obtain the required information."—*Mechanics' Magazine.*

"An invaluable compendium of scientific progress for which the public are indebted to the untiring energy of Mr. Timbs."—*Atlas.*

"There is not a more useful or more interesting compilation than the 'Year Book of Facts.' . . . The discrimination with which Mr. Timbs selects his facts, and the admirable manner in which he condenses into a comparatively short space all the salient features of the matters which he places on record, are deserving of great praise."—*Railway News.*

Science and Scripture.

SCIENCE ELUCIDATIVE OF SCRIPTURE, AND NOT ANTAGONISTIC TO IT; being a Series of Essays on—1. Alleged Discrepancies; 2. The Theory of the Geologists and Figure of the Earth; 3. The Mosaic Cosmogony; 4. Miracles in general—Views of Hume and Powell; 5. The Miracle of Joshua—Views of Dr. Colenso: The Supernaturally Impossible; 6. The Age of the Fixed Stars—their Distances and Masses. By Professor J. R. YOUNG, Author of "A Course of Elementary Mathematics," &c. &c. Fcap. 8vo, price 5*s.* cloth lettered.

"Professor Young's examination of the early verses of Genesis, in connection with modern scientific hypotheses, is excellent."—*English Churchman.*

"Distinguished by the true spirit of scientific inquiry, by great knowledge, by keen logical ability, and by a style peculiarly clear, easy, and energetic."—*Nonconformist.*

"No one can rise from its perusal without being impressed with a sense of the singular weakness of modern scepticism."—*Baptist Magazine.*

"The author has displayed considerable learning and critical acumen in combating the objections alluded to. . . . . The volume is one of considerable value, inasmuch as it contains much sound thought, and is calculated to assist the reader to discriminate truth from error, at least so far as a finite mind is able to separate them. The work, therefore, must be considered to be a valuable contribution to controversial theological literature."—*City Press.*

Geology and Genesis Harmonised.

THE TWIN RECORDS of CREATION; or, Geology and Genesis, their Perfect Harmony and Wonderful Concord. By GEORGE W. VICTOR LE VAUX. With numerous Illustrations. Fcap. 8vo, price 5*s.* cloth.

"We can recommend Mr. Le Vaux as an able and interesting guide to a popular appreciation of geological science."—*Spectator.*

"The author combines an unbounded admiration of science with an unbounded admiration of the Written Record. The two impulses are balanced to a nicety; and the consequence is, that difficulties, which to minds less evenly poised, would be serious, find immediate solutions of the happiest kinds."—*London Review.*

"Mr. Le Vaux very feasibly reconciles the two records."—*Builder.*

"A most instructive and readable book. We welcome this volume as aiding in a most important discussion, and commend it to those interested in the subject."—*Evangelical Magazine.*

"Vigorously written, reverent in spirit, stored with instructive geological facts, and designed to show that there is no discrepancy or inconsistency between the Word and the works of the Creator. The future of Nature, in connexion with the glorious destiny of man, is vividly conceived."—*Watchman.*

"A valuable contribution to the evidences of Revelation, and disposes very conclusively of the arguments of those who would set God's works against God's Word. No real difficulty is shirked, and no sophistry is left unexposed."—*The Rock.*

Wood-Carving.

INSTRUCTIONS in WOOD-CARVING, for Amateurs; with Hints on Design. By A LADY. In emblematic wrapper, handsomely printed, with Ten large Plates, price 2*s.* 6*d.*

"The handicraft of the wood-carver, so well as a book can impart it, may be learnt from 'A Lady's' publication."—*Athenæum.*

"A real *practical guide.* It is very complete."—*Literary Churchman.*

"The directions given are plain and easily understood, and it forms a very good introduction to the practical part of the carver's art."—*English Mechanic.*

"The writer of the little treatise before us deals very plainly and practically with her subject. . . . . The illustrations are admirably drawn, nearly all the patterns being remarkable for their graceful ornamentation. We can confidently recommend the book to amateur wood-carvers."—*Young Englishwoman.*

Popular Work on Painting.

PAINTING POPULARLY EXPLAINED; with Historical Sketches of the Progress of the Art. By THOMAS JOHN GULLICK, Painter, and JOHN TIMBS, F.S.A. Second Edition, revised and enlarged. With Frontispiece and Vignette. In small 8vo, 6*s.* cloth.

*** This Work has been adopted as a Prize-book in the Schools of Art at South Kensington.

"A work that may be advantageously consulted. Much may be learned, even by those who fancy they do not require to be taught, from the careful perusal of this unpretending but comprehensive treatise."—*Art Journal.*

"A valuable book, which supplies a want. It contains a large amount of original matter, agreeably conveyed, and will be found of value, as well by the young artist seeking information as by the general reader. We give a cordial welcome to the book, and augur for it an increasing reputation."—*Builder.*

"This volume is one that we can heartily recommend to all who are desirous of understanding what they admire in a good painting."—*Daily News.*

Delamotte's Works on Illumination & Alphabets.

A PRIMER OF THE ART OF ILLUMINATION; for the use of Beginners: with a Rudimentary Treatise on the Art, Practical Directions for its Exercise, and numerous Examples taken from Illuminated MSS., printed in Gold and Colours. By F. DELAMOTTE. Small 4to, price 9*s*. Elegantly bound, cloth antique.

"A handy book, beautifully illustrated; the text of which is well written, and calculated to be useful. . . . The examples of ancient MSS. recommended to the student, which, with much good sense, the author chooses from collections accessible to all, are selected with judgment and knowledge, as well as taste."—*Athenæum.*

ORNAMENTAL ALPHABETS, ANCIENT and MEDIÆVAL; from the Eighth Century, with Numerals; including Gothic, Church-Text, large and small, German, Italian, Arabesque, Initials for Illumination, Monograms, Crosses, &c. &c., for the use of Architectural and Engineering Draughtsmen, Missal Painters, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. &c. &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. Royal 8vo, oblong, price 4*s*. cloth.

"A well-known engraver and draughtsman has enrolled in this useful book the result of many years' study and research. For those who insert enamelled sentences round gilded chalices, who blazon shop legends over shop-doors, who letter church walls with pithy sentences from the Decalogue, this book will be useful."—*Athenæum.*

EXAMPLES OF MODERN ALPHABETS, PLAIN and ORNAMENTAL; including German, Old English, Saxon, Italic, Perspective, Greek, Hebrew, Court Hand, Engrossing, Tuscan, Riband, Gothic, Rustic, and Arabesque; with several Original Designs, and an Analysis of the Roman and Old English Alphabets, large and small, and Numerals, for the use of Draughtsmen, Surveyors, Masons, Decorative Painters, Lithographers, Engravers, Carvers, &c. Collected and engraved by F. DELAMOTTE, and printed in Colours. Royal 8vo, oblong, price 4*s*. cloth.

"To artists of all classes, but more especially to architects and engravers, this very handsome book will be invaluable. There is comprised in it every possible shape into which the letters of the alphabet and numerals can be formed, and the talent which has been expended in the conception of the various plain and ornamental letters is wonderful."—*Standard.*

MEDIÆVAL ALPHABETS AND INITIALS FOR ILLUMINATORS. By F. DELAMOTTE, Illuminator, Designer, and Engraver on Wood. Containing 21 Plates, and Illuminated Title, printed in Gold and Colours. With an Introduction by J. WILLIS BROOKS. Small 4to, 6*s*. cloth gilt.

"A volume in which the letters of the alphabet come forth glorified in gilding and all the colours of the prism interwoven and intertwined and intermingled, sometimes with a sort of rainbow arabesque. A poem emblazoned in these characters would be only comparable to one of those delicious love letters symbolized in a bunch of flowers well selected and cleverly arranged."—*Sun.*

THE EMBROIDERER'S BOOK OF DESIGN; containing Initials, Emblems, Cyphers, Monograms, Ornamental Borders, Ecclesiastical Devices, Mediæval and Modern Alphabets, and National Emblems. Collected and engraved by F. DELAMOTTE, and printed in Colours. Oblong royal 8vo, 2*s*. 6*d*. in ornamental boards.

AGRICULTURE, &c.

Youatt and Burn's Complete Grazier.

THE COMPLETE GRAZIER, and FARMER'S and CATTLE-BREEDER'S ASSISTANT. A Compendium of Husbandry. By WILLIAM YOUATT, ESQ., V.S. 11th Edition, enlarged by ROBERT SCOTT BURN, Author of "The Lessons of My Farm," &c. One large 8vo volume, 784 pp. with 215 Illustrations. *1l.* 1*s.* half-bd.

CONTENTS.

On the Breeding, Rearing, Fattening, and General Management of Neat Cattle.—Introductory View of the different Breeds of Neat Cattle in Great Britain.—Comparative View of the different Breeds of Neat Cattle.—General Observations on Buying and Stocking a Farm with Cattle.—The Bull.—The Cow.—Treatment and Rearing of Calves.—Feeding of Calves for Veal.—Steers and Draught Oxen.—Grazing Cattle.—Summer Soiling Cattle.—Winter Box and Stall-feeding Cattle.—Artificial Food for Cattle.—Preparation of Food.—Sale of Cattle.

On the Economy and Management of the Dairy.—Milch Kine.—Pasture and other Food best calculated for Cows, as it regards their Milk.—Situation and Buildings proper for a Dairy, and the proper Dairy Utensils.—Management of Milk and Cream, and the Making and Preservation of Butter.—Making and Preservation of Cheese.—Produce of a Dairy.

On the Breeding, Rearing, and Management of Farm-horses.—Introductory and Comparative View of the different Breeds of Farm-horses.—Breeding Horses, Cart Stallions and Mares.—Rearing and Training of Colts.—Age, Qualifications, and Sale of Horses.—Maintenance and Labour of Farm-horses.—Comparative Merits of Draught Oxen and Horses.—Asses and Mules.

On the Breeding, Rearing, and Fattening of Sheep.—Introductory and Comparative View of the different Breeds.—Merino, or Spanish Sheep.—Breeding and Management of Sheep.—Treatment and Rearing of House-lambs, Feeding of Sheep, Folding Sheep, Shearing of Sheep, &c.

On the Breeding, Rearing, and Fattening of Swine.—Introductory and Comparative View of the different Breeds of Swine.—Breeding and Rearing of Pigs.—Feeding and Fattening of Swine.—Curing Pork and Bacon.

On the Diseases of Cattle.—Diseases Incident to Cattle—Diseases of Calves.—Diseases of Horses.—Diseases of Sheep.—Diseases of Lambs.—Diseases Incident to Swine.—Breeding and Rearing of Domestic Fowls, Pigeons, &c.—Palmipedes, or Web-footed kinds.—Diseases of Fowls.

On Farm Offices and Implements of Husbandry.—The Farm-house, the Farmyard, and its Offices.—Construction of Ponds.—Farm Cottages.—Farm Implements.—Steam Cultivation.—Sowing Machines, and Manure Distributors.—Steam Engines, Thrashing Machines, Corn-dressing Machines, Mills, Bruising Machines.

On the Culture and Management of Grass Land.—Size and Shape of Fields.—Fences.—Pasture Land.—Meadow Land.—Culture of Grass Land.—Haymaking.—Stacking Hay.—Impediments to the Scythe and the Eradication of Weeds.—Paring and Burning.—Draining. Irrigation.—Warping.

On the Cultivation and Application of Grasses, Pulse, and Roots.—Natural Grasses usually cultivated.—Artificial Grasses or Green Crops.—Grain and Pulse commonly cultivated for their Seeds, for their Straw, or for Green Forage.—Vegetables best calculated for Animal Food.—Qualities and Comparative Value of some Grasses and Roots as Food for Cattle.

On Manures in General, and their Application to Grass Land.—Vegetable Manures.—Animal Manures.—Fossil and Mineral Manures.—Liquid or Fluid Manures.—Composts.—Preservation of Manures.—Application of Manures.—Flemish System of Manuring.—Farm Accounts, and Tables for Calculating Labour by the Acre, Rood, &c., and by the Day, Week, Month, &c.—Monthly Calendar of Work to be done throughout the Year.—Observations on the Weather.—INDEX.

"The standard, and text-book, with the farmer and grazier."—*Farmer's Magazine.*

"A valuable repertory of intelligence for all who make agriculture a pursuit, and especially for those who aim at keeping pace with the improvements of the age."—*Bell's Messenger.*

"A treatise which will remain a standard work on the subject as long as British agriculture endures."—*Mark Lane Express.*

Scott Burn's Introduction to Farming.

THE LESSONS of MY FARM: a Book for Amateur Agriculturists, being an Introduction to Farm Practice, in the Culture of Crops, the Feeding of Cattle, Management of the Dairy, Poultry, and Pigs, and in the Keeping of Farm-work Records. By ROBERT SCOTT BURN, Editor of "The Year-Book of Agricultural Facts," &c. With numerous Illustrations. Fcp. 6*s.* cloth.

"A most complete introduction to the whole round of farming practice."—*John Bull.*

"There are many hints in it which even old farmers need not be ashamed to accept."—*Morning Herald.*

Tables for Land Valuers.

THE LAND VALUER'S BEST ASSISTANT: being Tables, on a very much improved Plan, for Calculating the Value of Estates. To which are added, Tables for reducing Scotch, Irish, and Provincial Customary Acres to Statute Measure; also, Tables of Square Measure, and of the various Dimensions of an Acre in Perches and Yards, by which the Contents of any Plot of Ground may be ascertained without the expense of a regular Survey; &c. By R. HUDSON, Civil Engineer. New Edition, with Additions and Corrections, price 4*s.* strongly bound.

"This new edition includes tables for ascertaining the value of leases for any term of years: and for showing how to lay out plots of ground of certain acres in forms, square, round, &c., with valuable rules for ascertaining the probable worth of standing timber to any amount; and is of incalculable value to the country gentleman and professional man."—*Farmer's Journal.*

The Laws of Mines and Mining Companies.

A PRACTICAL TREATISE on the LAW RELATING to MINES and MINING COMPANIES. By WHITTON ARUNDELL, Attorney-at-Law. Crown 8vo. 4*s.* cloth.

Auctioneer's Assistant.

THE APPRAISER, AUCTIONEER, HOUSE AGENT, and HOUSE BROKER'S POCKET ASSISTANT. By JOHN WHEELER, Valuer. A new edition, much improved and enlarged, and entirely re-written. [*In preparation.*

The Civil Service Book-keeping.

BOOK-KEEPING NO MYSTERY: its Principles popularly explained, and the Theory of Double Entry analysed; for the use of Young Men commencing Business, Examination Candidates, and Students generally. By an EXPERIENCED BOOK-KEEPER, late of H.M. Civil Service. Second Edition. Fcp. 8vo. price 2*s.* cloth.

"A book which brings the so-called mysteries within the comprehension of the simplest capacity."—*Sunday Times.*

"It is clear and concise, and exactly such a text-book as students require."—*Quarterly Journal of Education.*

Text-Book for Architects, Engineers, Surveyors, Land Agents, Country Gentlemen, &c.

A GENERAL TEXT-BOOK for ARCHITECTS, ENGINEERS, SURVEYORS, SOLICITORS, AUCTIONEERS, LAND AGENTS, and STEWARDS, in all their several and varied Professional Occupations; and for the Assistance and Guidance of Country Gentlemen and others engaged in the Transfer, Management, or Improvement of Landed Property; together with Examples of Villas and Country Houses. By EDWARD RYDE, Civil Engineer and Land Surveyor. To which are added several Chapters on Agriculture and Landed Property, by Professor DONALDSON, Author of several works on Agriculture. With numerous Engravings, in one thick vol. 8vo, price 1*l.* 8*s.* cloth.

CONTENTS.

ARITHMETIC.
PLANE AND SOLID GEOMETRY.
MENSURATION.
TRIGONOMETRY.
CONIC SECTIONS.
LAND MEASURING.
LAND SURVEYING.
LEVELLING.
PLOTTING.
COMPUTATION OF AREAS.
COPYING MAPS.
RAILWAY SURVEYING.
COLONIAL SURVEYING.
HYDRAULICS IN CONNECTION WITH DRAINAGE, SEWERAGE, AND WATER SUPPLY.
TIMBER MEASURING.
ARTIFICERS' WORK.
VALUATION OF ESTATES.
VALUATION OF TILLAGE AND TENANT RIGHT.
VALUATION OF PARISHES.
BUILDERS' PRICES.
DILAPIDATIONS AND NUISANCES.
THE LAW RELATING TO APPRAISERS AND AUCTIONEERS.
LANDLORD AND TENANT.
TABLES OF NATURAL SINES AND COSINES; FOR REDUCING LINKS INTO FEET, &c. &c.
STAMP LAWS.
EXAMPLES OF VILLAS, &c.

To which are added Fourteen Chapters

ON LANDED PROPERTY. By PROFESSOR DONALDSON.

Chap. I.—Landlord and Tenant: their Position and Connections.
Chap. II.—Lease of Land, Conditions and Restrictions; Choice of Tenant, and Assignation of the Deed.
Chap. III.—Cultivation of Land, and Rotation of Crops.
Chap. IV.—Buildings necessary on Cultivated Lands: Dwelling-houses, Farmeries, and Cottages for Labourers.
Chap. V.—Laying out Farms, Roads, Fences, and Gates.
Chap. VI.—Plantations, Young and Old Timber.
Chap. VII.—Meadows and Embankments, Beds of Rivers, Water Courses, and Flooded Grounds.
Chap. VIII.—Land Draining, Opened and Covered: Plan, Execution, and Arrangement between Landlord and Tenant.
Chap. IX.—Minerals, Working, and Value.
Chap. X.—Expenses of an Estate.
Chap. XI.—Valuation of Landed Property; of the Soil, of Houses, of Woods, of Minerals, of Manorial Rights, of Royalties, and of Fee Farm Rents.
Chap. XII.—Land Steward and Farm Bailiff: Qualifications and Duties.
Chap. XIII.—Manor Bailiff, Woodrieve, Gardener, and Gamekeeper: their Position and Duties.
Chap. XIV.—Fixed Days of Audit: Half-yearly Payments of Rents, Form of Notices, Receipts, and of Cash Books, General Map of Estates, &c.

"No Englishman ought to be without this book."

EVERY MAN'S OWN LAWYER; a Handy-Book of the Principles of Law and Equity. By A BARRISTER. 8th Edition, carefully revised, including a Summary of the New Bankruptcy Laws, the Fraudulent Debtors Act, an Abridgment of the principal Statute Laws of the last Session, and the Reported Cases of the Courts of Law and Equity. With Notes and References to the Authorities. 12mo, price 6*s.* 8*d.* (saved at every consultation), strongly bound. [*Just published.*

Comprising the Rights and Wrongs of Individuals, Mercantile and Commercial Law, Criminal Law, Parish Law, County Court Law, Game and Fishery Laws, Poor Men's Lawsuits,

THE LAWS OF

BANKRUPTCY.	MORTGAGES.
BILLS OF EXCHANGE.	SETTLEMENTS.
CONTRACTS AND AGREEMENTS.	STOCK EXCHANGE PRACTICE.
COPYRIGHT.	TRADE MARKS AND PATENTS.
DOWER AND DIVORCE.	TRESPASS, NUISANCES, ETC.
ELECTIONS AND REGISTRATION.	TRANSFER OF LAND, ETC.
INSURANCE.	WARRANTY.
LIBEL AND SLANDER.	WILLS AND AGREEMENTS, ETC.

Also Law for

Landlord and Tenant.	Clergymen, Churchwardens.
Master and Servant.	Medical Practitioners, &c.
Workmen and Apprentices.	Bankers.
Heirs, Devisees, and Legatees.	Farmers.
Husband and Wife.	Contractors.
Executors and Trustees.	Stock and Share Brokers.
Guardian and Ward.	Sportsmen and Gamekeepers.
Married Women and Infants.	Farriers and Horse-Dealers.
Partners and Agents.	Auctioneers, House-Agents.
Lender and Borrower.	Innkeepers, &c.
Debtor and Creditor.	Pawnbrokers.
Purchaser and Vendor.	Surveyors.
Companies and Associations.	Railways and Carriers,
Friendly Societies.	&c. &c.

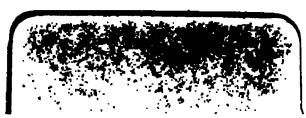
"*No Englishman ought to be without this book* . . . any person perfectly uninformed on legal matters, who may require sound information on unknown law points, will, by reference to this book, acquire the necessary information; and thus on many occasions save the expense and loss of time of a visit to a lawyer."—*Engineer*, Jan. 28, 1870.

"It is a complete code of English Law, written in plain language which all can understand . . . should be in the hands of every business man, and all who wish to abolish lawyers' bills."—*Weekly Times*, March 6, 1870.

"With the volume before us in hand, a man may, in nine cases out of ten, decide his own course of action, learn how to proceed for redress of wrongs, or recovery of rights, and save his pocket from the dreaded consultation fees and the incalculable bills of costs."—*Civil Service Gazette*, May 23, 1868.

"We have found it highly satisfactory as a work of authority and reference, and a handy-book of information. There is abundance of cheap and safe law in this work for all who want it."—*Rock*, May 26, 1868.

"A useful and concise epitome of the law, compiled with considerable care."—*Law Magazine.*

"What it professes to be—a complete epitome of the laws of this country, thoroughly intelligible to non-professional readers. The book is a handy one to have in readiness when some knotty point requires ready solution."—*Bell's Life.*

BRADBURY, EVANS, AND CO., PRINTERS, WHITEFRIARS.